INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE

COMMISSION INTERNATIONALE DES IRRIGATIONS ET DU DRAINAGE

SEVENTH CONGRESS 1969 GENERAL REPORT (E)
SEPTIEME CONGRES 1969 QUESTION 23

WATER REQUIREMENTS OF CROPS

MARVIN E. JENSEN*

GENERAL REPORTER

This subject is basic to the planning and designing of irrigation projects and it is also basic to the management of individual farms or fields, although the latter has received less attention. Researchers have studied water requirements of plants intensively since about 1890, and voluminous data are available. The ICID reports presented on this question represent some, but not all of the research that has been conducted or is underway in many countries. The response to this question, 43 reports from 19 countries, is an indication of the tremendous effort that is underway to determine and refine the water requirements of crops. A comprehensive search and review of all water-requirement data by individual crops would probably reveal sufficient detail to enable optimum management of irrigation water for each crop under any climatic and soil regime provided supporting data are available to enable interpretation and adaption to specific regimes.

I. DEFINITIONS

There are two primary parameters that affect water requirements per unit land area—consumptive use or evapotranspiration, and deep percolation. Definitions of these parameters, as presented in the ICID Multilingual Dictionary on Irrigation and Drainage, are given below because they are

* Research Investigations Leader, Water Management Northwest Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Kimberly, Idaho, USA.

important to the interpretation of this report.

Consumptive Use or Evapotranspiration—"The quantity of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from the soil or from intercepted precipitation on the area in any specified time. It is expressed in water-depth units or depth-area units per unit area."

Deep Percolation—"With respect to irrigation and precipitation, that amount of water which passes below the root zone of crops or vegetation."

The magnitude of daily evapotranspiration is controlled primarily by meteorological conditions when a green crop has sufficient leaf area and soil moisture so as not to limit E_t. In contrast, the magnitude of deep percolation is influenced by the amount of irrigation water applied at each irrigation, precipitation, soil characteristics, and the soil moisture level maintained. The major impact of these parameters on reported water requirements is that *evapotranspiration is limited at any time by the heat energy available for evaporation and tends to fall within predictable limits.* In contrast, *deep percolation is not so limited, but may vary widely depending on irrigation practices and the management of the system.* As the result, evapotranspiration data for a given crop will be similar in area of similar climate and growing seasons, but if reported water requirement data represent E_t plus deep percolation, much greater variations are encountered. Also, since these variations are influenced by man, they are less predictable.

II. INTERPRETING AND UTILIZING REPORTED VALUES OF WATER REQUIREMENTS OF CROPS

Valid comparisons of water requirement data are provided only if the E_t component is evaluated separately since it is controlled by the crop, climate, and soil moisture level. Most authors proceeded on this basis. Many reports presented average E_t rates for specific time periods, peak rates, mean monthly rates, seasonal totals. Some included a measure of evaporative demand, such as an estimate of potential evapotranspiration or observed evaporation. Greater unification of these data would have been possible if each reported value of E_t was accompanied by some measure of the evaporative demand that existed during the period of measurement. At any time during the season, the upper limit of E_t is controlled by meteorlogical conditions when a green crop has adequate foliage and soil moisture. The upper limit, on a daily basis, can be defined as potential evapotranspiration, E_{tp}. The potential rate can either be measured or estimated in an area. Because of the large amount of heat required to evaporate water, estimating methods based on the conservation of energy or "energy balance" are the most reliable and conservative, even for daily values. There are two sources of heat energy for an irrigated field within an irrigation project—solar radiation and sensible heat from the air. As much as 30 to 40 per cent (R. 21 presents data from Syria indicating about 75 per cent) of the heat energy absorbed during July and August by a well-irrigated crop within an irrigation project surrounded by arid lands may come from sensible heat transferred to the field by the air mass (advected energy). In contrast, significant advected energy seldom occurs in a semi-humid or humid area.

A. SUPPORTING METEOROLOGICAL AND CULTURAL DATA

Greater utilization and direct transfer of E_t data obtained by time-consuming, expensive research is also possible when basic meteorological data are included for the experimental site. These data, presented for 10-day or monthly periods during the growing season, should include :

Preferable meteorological data

Mean maximum air temperature in °C

Mean minimum air temperature in °C

Mean solar radiation in calories cm^{-2} day^{-1}

Mean humidity, expressed as vapour pressure, in mb

Mean wind speed, preferably measured at a 2 m height in km hr^{-1}

Mean cloud cover in 10ths

Mean precipitation in mm.

Alternate data

Net radiation in calories cm^{-2} day^{-1} in lieu of solar radiation and cloud cover

Percentage of possible sunshine in lieu of solar radiation.

Evaporation from a standard pan surrounded by well-watered grass in mm day^{-1}.

Many, but not all of the reports on Question 23 included these data (R. 17 and R. 23 are excellent examples). Greater future progress would be attained if all publications of E_t data from world-wide locations would include a summary of meteorological data for the site which would enable researchers to compare their results with those of others obtained under similar climatic conditions. Maximum and minimum air temperatures can be very useful when other climatic data are not available. Minimim air temperatures for example, can be used to approximate dew point temperatures or humidity(1). Mean, minimum temperatures also define the effective growing season for many crops grown in the area.

B. GENERALIZING EVAPOTRANSPIRATION DATA

One approach that will promote greater extrapolation of E_t data, is the use of a crop coefficient that is primarily a function of stage of growth and a standardized reference. Several reports presented coefficients relating observed evapotranspiration to evaporation (R. 8, R. 10 and R. 35). Others presented coefficients retating E_t to various estimates of potential evapotranspiration. A coefficient relating E_t for a crop to a standard well-watered reference crop, such as alfalfa, with at least 30-50 cm of growth represents the following daily energy balance parameters (2)

(1) JENSEN, M. E. "Empirical methods of estimating or predicting evapotranspiration using radiation," Conference Proc., Evapotranspiration and its Role in Water Resources Management, Dec 5-6, 1966, Chicago, Illinois, Published by Amer. Soc. of Agr. Engrs., St. Joseph, Michigan.

(2) JENSEN, M. E., "Water consumption by agricultural plants," Chapter 1 Water Deficits and Plant Growth, Vol. II, T. Z. Kozlowsky, Ed., pp 1-22, Academic Press New York, New York; 1968.

$$K_c = \frac{R_n + A + G}{R_{no} + A_o + G_o} = \frac{1 + \beta_o}{1 + \beta} \frac{(R_n + G)}{(R_{no} + G_o)} \quad ...(1)$$

in which R_n is net radiation, A is sensible heat flux to or from the air, G is sensible heat flux to or from the soil, and β represents the ratio of sensible heat flux to latent heat flux A/E_t (the Bowen ratio). The subscript "o" designates concurrent values for the reference crop in the immediate vicinity. The energy terms are positive for input to the crop-air zone and negative for outflow. With experience and some data, such as those presented in R. 1. and R. 36, engineers and agronomists can estimate K_c values for crops grown in their regions. Then with observed or estimated potential evapotranspiration, E_t can be estimated for most crops as follows :

$$E_t = K_c \, E_{tp} \quad ...(2)$$

Other reports that included crop coefficients are : R . 2, 3, 8, 10, 20, 21, 34, and 35. Numerous other reports presented data that would enable the E_t and yield data to be generalized (R. 1, 12, 17, 29, 32, 33, 36, 38 and 42).

C. METHODOLOGY EFFECTS

The method used to determine E_t can significantly influence the values obtained. Frequently, unusually high or low E_t values can be directly attributed to the methodology used.

1. Soil moisture depletion

The most common method of determining E_t rates under natural environmental conditions which has been used over 70 years, is gravimetric soil sampling 2 to 3 days after an irrigation and again in 5 to 20 days, or just before the next irrigation. More recently, the neutron soil moisture probe has been employed. From the change in soil moisture and rainfall received during the interval the average E_t rate for the period is calculated as follows :

$$E_t = \frac{W_{et}}{\triangle t} = \frac{-\sum_{0}^{S_r} \triangle \theta \triangle S + R_e - W_d}{\triangle t} \quad ...(3)$$

in which W_{et} = the total water used in evapotranspiration, S = the distance from the soil surface, S_r = the depth of the effective root zone, $\triangle\theta$ = the volumetric change in soil moisture (a negative sign indicating a decrease), R_e = effective rainfall, $\triangle t$ = the time interval between sampling dates (usually days), E_t = the average evapotranspiration rate, and W_d = the water drained from the 0 to S_r depth. Drainage from the effective root zone or upward movement into the effective root zone is the major unknown in Equation (3) and is generally assumed to be zero. The drainage component tends to be larger in the spring and fall when E_t rates are low (see R. 17). Consequently, many measurements of E_t rates during the season show more uniform rates than would be indicated by potential evapotranspiration. One report included corrections for drainage (R. 17).

Most reported E_t values were determined by soil moisture depletion using gravimetric techniques, the soils were sampled 1-2 days after an irrigation and again just before the next irrigation. Others sampled at regular intervals, such as every 10 days, and then added both the rainfall and irrigation water applied. This approach produces reliable results when the amount of water applied at each irrigation was less than the amount required to bring the soil to field capacity. The value of field capacity itself is dependent on the amount of water applied, *i.e.*, under normal irrigations, field capacity as determined after excessive irrigation is usually not attained. As the result, irrigations calculated to bring a soil to field capacity usually results in deep percolation which can significantly influence E_t determinations when the irrigation amount is added in the calculation of E_t.

2. Lysimetry

When properly installed, operated, and instrumented, lysimeters provide the most accurate measurement of evapotranspiration. This is especially true under high rainfall conditions, because the probable error resulting from drainage increases with moisture depletion techniques. The major sources of errors in E_t data obtained with lysimeters are: (1) the vegetative and soil moisture conditions in the lysimeter may not be comparable to those of the surrounding crop; (2) the effective leaf area for the interception of radiation and transpiration may be greater than the surface area of the lysimeter, *i.e.*, the foliage may extend beyond the perimeter of the lysimeter or extend above the surrounding crop; and (3) the edge of the lysimeter may represent an excessively large proportion of the surface area of the lysimeter, resulting in unrealistic border effects caused by the lysimeter itself. This effect can influence the microclimate in the plant-air zone. A well-designed lysimeter, properly installed and surrounded by the same crops, may be the only practical method of measuring E_t from a flooded rice field (R. 38).

A general summary of the various methods of measuring or determining evapotranspiration is presented in R. 38.

III. OBSERVED EVAPOTRANSPIRATION

A. GROWTH STAGE AND SOIL MOISTURE EFFECTS

About 60 per cent of the reports presented E_t data for various stages of crop growth and soil moisture levels. However, many of the reported values represent the combined effects of growth stage and evaporative demand. The rate of E_t during the flowering stage of wheat, for example, may be only 3-4 mm per day when this stage occurs in February or March (winter wheat), but may be 6-7 mm per day if this stage occurs in June (summer wheat). This difference is not due to the characteristics of the crop, but is primarily due to the difference in evaporative demand when this growth stage occurs. All differences in E_t rates reported for similar crops should be considered in this respect. Report 38 typically illustrates how climate can influence E_t rates for rice planted at different times during the growing season. The following reports present data on this sub-topic: R. 1, 2, 3, 8, 11, 13, 16, 17, 18, 19, 20, 21, 23, 24, 29, 30, 32, 33, 35, 36, 37, 38, 39, 41, 42 and 43.

B. MAXIMUM E_t RATES

Maximum E_t rates for most summer crops in all areas ranged from 7.5 to 8.5 mm per day. An exception (13-14 mm per day) was reported for Syria (R. 21) which may be largely attributed to high winds causing severe advection of energy from the surrounding dry areas. Maximum rates for winter crops were 2-3 mm/day in February, 3-4 mm/day in March, and 4-5 mm/day in April and May. These data support the hypothesis that peak rates are largely determined by climatic rather than crop characteristics. The following reports present data on maximum E_t rates :

R. 1, 2, 3, 4, 8, 17, 18, 19, 21, 23, 24, 29, 38, 41 and 42.

C. SEASONAL E_t

Seasonal E_t varies more for a given crop because two variables are involved : (1) Evapotranspiration rates, and (2) the duration of the growing season. Direct adaptation of seasonal E_t for a crop should only be made for similar climatic zones in which the planting and maturing dates are similar. Report 38 clearly illustrates the influence of the duration of a growing season on total E_t for rice. Some reports present seasonal water requirements which are based on the amount of water applied and not E_t. These data should not be interpreted as seasonal E_t data. The following reports present seasonal data : R. 1, 2, 3, 4, 11, 12, 17, 18, 20, 21, 23, 24, 25, 29, 32, 33, 35, 36, 38, and 39.

IV. RESPONSES TO SUPPLEMENTAL IRRIGATIONS

A. YIELD EFFECTS

During the last decade, numerous irrigation studies have been conducted in areas where crops can be grown with soil moisture provided by rainfall. The major objectives of these studies were :

(1) To determine whether irrigation is necessary for maximum production, and if necessary, (2) to determine if irrigation is economically feasible. Other studies attempted to delineate the most practical and beneficial irrigation practices, the most critical stages of growth, and yield increases directly attributable to supplemental irrigations. (See Reports : 1, 4, 5, 11, 13, 15, 18, 26, 28, 30 and 43.)

B. FERTILIZER INTERACTIONS

Increased yields obtainable with supplemental irrigations require additional plant nutrients. Benefits from supplemental irrigations may not have been attained if adequate fertilizer had not been provided. Reports 3, 15, 16 and 20 summarize the effects of fertilizer levels on crop yields.

V. SOIL MOISTURE LEVELS

Most of the experiments covered in the reports on Question 23 involved irrigation treatments that directly or indirectly were based on soil moisture levels. Several methods of characterizing moisture levels or its equivalent were used. The most common treatments were based on the depletion of available soil moisture to specific levels. These levels were determined by gravimetric soil sampling, soil moisture blocks (electrical resistance blocks), and tensiometers. Other treatments that induced different soil moisture conditions were :

(1) Prescribed schedules of irrigations, and (2) irrigations based on various fractions of estimated E_t. One of the objectives of soil moisture level treatments was to determine the optimum levels for a given crop and climate (See Reports 9, 17, 21 and 34).

VI. WATER USE EFFICIENCY

About 25 per cent of the reports presented water use efficiency data (production per unit volume of water or its inverse, water use per unit weight of dry matter produced). However, interpretations or comparisons of these data must be made with care because many different methods were used to calculate these values such as : (1) Production per unit volume of total E_t, (2) increased production per unit of increased E_t as compared to non-irrigated crops, (3) production per unit volume of water applied including rainfall, and (4) increased production as compared to non-irrigated land per unit volume of irrigation water applied. In general, fertilizer increased water use efficiency because yields increased with fertilizer applications without a proportionate increase in E_t. (See Reports 1, 3, 4, 5, 7, 14, 15, 16, 26, 31 and 35.)

VII. GENERALIZATION OF RESULTS AND IRRIGATION PRACTICES

Several reports presented general discussions of crop water requirements, the factors affecting E_t, the use of E_t data in project planning and management, and summaries of general irrigation practices. (See Reports 6, 7, 9, 22, 27, 28, 31, 36 and 40.)

VIII. FUTURE RESEARCH

Only a few reports presented specific ideas or suggestions for future research. Many of these involved the expansion or completion of current studies. Several reports presented long-range plans for future studies. (See Reports 9, 17, 20, 24, 26, 32 and 37.)

IX. SUMMARY AND COMMENTS ON EACH REPORT

The individual report summaries were prepared to describe briefly the nature of the study and the primary results obtained. Specific questions were raised to stimulate discussions of controversial or questionable items, and to bring forth clarifications of vague statements, or missing important information.

REPORT 1 : **The determination of water requirements of crops—by Jean-Marie Pouzoulet (France)**

This report meticulously describes procedures for generalizing evapotranspiration data as described under section II B, and also includes production relationships that permit the selection and application of the optimum levels of irrigation. The Provence and Provençale Region Management Company tried several methods of providing water requirement data to the farmers before selecting this method. Soil moisture inventory methods were initiated in 1959, but these proved to be complicated and expensive and relatively imprecise.

The method selected involves three phases: (1) Measurement of a crop's maximum real evapotranspiration, E_t, using lysimeters surrounded by the same crop which is watered at the same frequency; (2) Determination of the economic optimum level of watering using 5 replications of treatments (unit plot size was 5 m $\times$ 6 m) irrigated at 100 per cent, 80 per cent and 60 per cent of E_t plus a non-irrigated treatment. The unit application for each treatment varied with root development, but was the same for all treatments. Only the frequency differed from one treatment to another; (3) The results of the first two phases were related by a reference value, which in this case was potential evapotranspiration, E_{tp}, calculated by the Bouchet formula. The correction coefficient so obtained represents (E_t/E_{tp}) 100. The Bouchet formula is: $E_{tp}=\alpha E_p\lambda(\theta)$, where $\alpha=0.37$ for the English shelter, E_p=evaporation measured by the Piche evaporimeter, and $\lambda(\theta)$ is a function of the air and dew point temperatures.

Studies conducted during the past four years using 8 lysimeters and three crops—tomatoes, potatoes and sorghum—are described in detail in the remainder of the report.

The relationship between E_t and E_{tp} was evaluated for several growth periods for each of the crops. The results from the field experiments indicated that tomatoes and potatoes should be irrigated at 100 per cent E_t for maximum production, and the optimum level for sorghum was between 67 and 80 per cent E_t.

This procedure for estimating water requirements has resulted in improved distribution of water requirement data, and represents a general advancement in irrigation water management. Additional data on climatic conditions under which (E_t/E_{tp}) 100 values were derived are still desired, however, especially shortly after planting until after full crop cover is attained. The values reported just after planting were about 50 per cent, whereas in semiarid areas where little or no rainfall is received, the (E_t/E_{tp}) 100 values may be as low as 20 per cent because of a dry surface soil layer. Frequent rainfall is expected to increase E_t/E_{tp} values during partial cover growth stages. Thus the E_t/E_{tp} values probably will be dependent on climatic conditions.

REPORT 2: **An investigation of the consumptive use of water for crops and the frequency of irrigation in the United Arab Republic—by Mamdouh Shahin and Mohamed I. El-Shal (U.A.R.)**

This report reviews previous irrigation water requirement criteria established for Egypt in 1899 and revised in 1920, general irrigation practices, studies on water requirements of crops conducted during the past two decades, and an approach to estimating the frequency of irrigation. Two groups of experiments are summarized. The first experiments were conducted from 1953 to 1956 using plots approximately 7.5 m square for determining water use by cotton, wheat, early corn, late corn, berseem, and citrus. Evapotranspiration was determined by the soil moisture depletion method, sampling at 10-cm intervals to a depth of 60 cm. Extraction of water to greater depths was estimated by extrapolation. Water was measured to each plot using a weir or a flow meter. The second group of experiments involved the determination of the optimum irrigation frequency for cotton and corn during the same period. An excellent summary of climatic conditions by months for each of the stations is presented. The soil at each experimental site is very homogeneous and uniform to a depth of 1.5 m. The clay and silt content is about 85 per cent for the stations north of Cairo while those near and south of Cairo contain 55 to 65 per cent clay and silt.

Detailed E_t rates with supporting data for cotton are presented along with moisture depletion-time curves for the various depth increments. The maximum rate of E_t (7-8 mm per day) for cotton occurred during the latter part of June and first part of July. Similar E_t curves are presented for wheat, early and late corn, berseem, and citrus. Peak E_t rates for wheat occurred in March and averaged about 3 mm per day. Peak rates for corn ranged from 6 to 7 mm per day during the latter part of June to the latter part of September depending on date of planting. Peak E_t rates for berseem (Egyptian clover) occurred from March through April and varied from 4 to 5 mm per day. The peak E_t rate for citrus orchards occurred in July and averaged approximately 4.5 mm per day. A summary of equations for estimating pan evaporation is presented along with ratios between mean monthly E_t for crops and pan evaporation.

The authors also calculated and presented crop coefficients for use with Blaney-Criddle, Penman, and Olivier formulas. They developed and presented a formula which involves a constant crop factor—"the Cairo formula". Equations for the crop coefficients for this formula are also presented.

From the experimental results on the frequency of irrigation, the authors present recommended intervals between irrigations, for the period June-September for each of the four regions in Egypt and for the various types of soils encountered. The effect of irrigation frequency on yield of cotton and corn indicated that a 15-day interval resulted in optimum yield of cotton, with 12 days for late corn and 11 days for early corn. The authors generally concluded that the proposed rotations, using a constant interval from June to September, should be adopted whereas the frequencies for the remainder of the year appear to be compatible with existing schedules.

REPORT 3: **The effect of soil moisture regime, phosphorus and nitrogen applications on the consumptive use of some crops in Assiut (UAR). Part I—The effect of soil moisture regime and phosphorus application on the consumptive use of water of legume crops in Assiut. Part II—The effect of nitrogen application on the annual consumptive use of some crops in Assiut—by Mohamed Hilmy El-Gibaly (UAR).**

Part I—This report summarizes research conducted on the farm of the Faculty of Agriculture, University of Assiut, during 1965 and 1966 to determine the effect of phosphorus on evapotranspiration using several legume crops (fenugreek, chick pea, lentil and the Egyptian lupin). Two experiments were involved. In the first, irrigation water was applied only at planting while in the second the water was applied three times after planting on fenugreek and Egyptian lupin, and two times on chick pea and lentil.

Phosphorus was applied to both experiments at a rate of zero and 100 kg superphosphate per feddan (a feddan=4,200.6 m^2). Each treatment was replicated three times in a randomized complete block. All crops were planted on November 10 and harvested from March 11 to March 15. The consumptive use of water was determined by soil samples taken at 10-cm increments to a depth of 50 cm just before and 48 hours after an irrigation.

Phosphorus fertilizer had no effect on E_t. The total E_t for fenugreek, lupin, lentil and chick pea was 273, 270, 220 and 215 mm, respectively. Since phosphorus fertilizer increased the yields of the various crops without an appreciable change in water use, the water use efficiency or production per unit of water increased with the use of phosphorus.

The second experiment was conducted at the same site during 1964-65 and 1965-66. The first part of this work involved the effect of nitrogen application on consumptive use of water with summer and winter crops. Summer crops were sugar cane, cotton, maize, and sorghum. Winter crops were wheat and barley. Another portion of the work involved the combined effects of nitrogen and phosphorus fertilizer on consumptive use of water with horse beans and berseem. A Latin square design was used in the first part of the experiment while a randomized complete block was used for the horse beans and berseem. E_t rates were calculated in the same manner as in Part I. Nitrogen was applied at 0, 45, and 80 kg N per feddan.

Nitrogen fertilizer also had no effect on consumptive use of sugar cane, cotton, maize, sorghum, wheat and barley. Average seasonal totals were 1750, 1033,640 564, 287, 240,711 and 316 mm for sugar cane, cotton, maize, sorghum, wheat, barley, berseem and horse beans, respectively. Since nitrogen fertilizer also did not increase water use, the water use efficiency increased with the application of nitrogen fertilizer. Maximum water use rates ranged from 7 to 8 mm per day for cotton, maize and sorghum and about 9 mm per day for sugar cane. The author found that the greatest portion of roots were located in the top 30-cm of soil and that 90 per cent or more of soil moisture depletion by most crops occurred in the top 40-cm.

Monthly and seasonal k values for the Blaney-Criddle formula are presented for fenugreek, lupin, lentil and chick pea and seasonal K values are presented for all crops.

REPORT 4: Water requirements of maize in the region of Coteaux de Gascogne—by Pierre Cavalan (France)

This report summarizes the results of irrigation trials conducted since 1959 on maize to determine: (1) the increase in yields due to irrigation, (2) characteristics of successful irrigation, and (3) data required for irrigation planning. The test plots (12 m × 12 m) were irrigated with sprinklers when 70 per cent of the available water had been depleted in the 15 to 30 cm depth. Gravimetric soil samples were used to determine the amount of depletion. A neutron probe was used in 1967. Precipitation in the study area averages 300 mm from May through September.

A comparison of the yields and water use efficiencies obtained when irrigating to replenish the 25 and 60 cm depths is presented which indicated that there was very little difference in yields, but water use efficiency was greater with less frequent irrigations. A comparison of irrigations to replenish the 60 cm and 90 cm depths in 1965-1966 also showed very little differences in both yields and water use efficiency.

A comparison of consumptive use and estimates of potential E_t made with the formulas of Turc, Thornthwaite, Blaney-Criddle, and Bouchet (since 1965), indicated that the observed cumulative consumptive use estimates for June-September were very close, but monthly deviations varied from 11 to 23 per cent. The total E_t was lower than that indicated by Blaney-Criddle. However, the Blaney-Criddle estimates were best for July and August. The author concludes that these formulas would be useless for 10-day values.

The results of the study indicate that adequate soil moisture should be provided from planting to the dough stage. About 500 mm of water is required in this area on this soil which can be supplied in two out of three years with only two irrigations of about 60 mm each. Data for economic evaluation are also provided along with mean E_t for the months of May-September. Peak monthly E_t rates were 3.7 mm per day in July and 4.0 mm per day in August.

REPORT 5 : **Results of the trials of water dosage fractioning in the irrigation by sprinkling and the effect of wind-break planting under special conditions of the Hardt region—by R. Specty and P. Gendrin (France)**

This report summarizes the results of irrigation trials in which water was applied at different soil moisture deficits (estimated potential evapotranspiration minus rainfall), and where windbreaks were planted to reduce the estimated potential evapotranspiration (E_{tp}). The soils in the area contain about 50 per cent sand, and have a low water holding capacity. As soon as the plants began to emerge, the authors assumed the soil to be fully covered by a crop in order to estimate the moisture deficits. E_{tp} was estimated using lysimeters and the Bouchet formula in 1963 and the Bouchet formula and observations with Piche evaporimeters under "Cauvi" shelters in 1964 and 1965 to estimate the reduction due to the windbreaks. Sunflowers, two rows spaced 24 m apart, were 2 m tall at the bloom stage of potatoes. The two rows of dead reeds were used in 1964 on potatoes and barley. Only partial replications were used (one for windbreaks in 1963, two for potatoes and one for barley in 1964 and 1965). Nitrogen rates on barley were used in 1964 and on wheat in 1965. The water used and water use efficiency refers to the water applied, and not consumptive use.

Irrigation increased potato yields each year, and barley yields in 1964. The windbreaks tended to increase yields. Very frequent irrigations increased the yield of commercial potatoes in 1963 and 1965.

The authors question the lack of response in allowing the estimated soil moisture deficit to approach the acceptable limit. However, the method used (assuming full crop cover throughout the season) would overestimate the deficit. The increase in water use efficiency attributed to windbreaks (less water applied) could also be attributed merely to a lower "excesss" application in the plots with windbreaks.

REPORT 6 : **Application of consumptive uses to the operation of irrigation districts—by Prudenico Mora Mamirez and Xavier Uriza Salgado (Mexico)**

In this paper the authors emphasize the importance of knowing the efficiencies of the major and minor conveyance network, irrigation efficiency, and the general efficiency of the district. Reliable determinations of these efficiencies require improvement in irrigation water measurement and knowledge of consumptive use. The authors illustrate how consumptive use data can be consolidated and utilized in the operation of irrigation districts. Estimated consumptive use values for 12 different farm crops were plotted beginning with the planting date irrespective of the absolute date of planting. Two curves, representing two general groups of cumulative data, were then derived. The authors expressed the opinion that since the conveyance efficiency may be under 50 per cent for earth canals and less than 70 per cent for lined canals, and if a variety of crops are grown, a single representative curve for high consumptive use crops and a curve for low consumptive use crops would be adequate for the operation of the system. They further concluded that the two representative curves justify the recommendations suggested by experience that equal levels and frequency of irrigation for different farm products are suitable, and the only variation needed is the number of irrigations required. In this case, the consumptive use averaged 3.3 mm per day for the low consumption crops and 4.5 mm per day for the high consumption crops. All of the summer crops belonged to the second group. They further rationalized this approach by stating that the error in the suggested curves is admissible because of the magnitude and statistical nature of the consumptive use data when compared with conveyance losses and over irrigation. They claim the following advantages for such an approach : (1) It makes it easier to determine the approximate requirements of any farm product insofar as consumptive use and efficiency are concerned if only its vegetative cycle and planting date are known ; and (2) these curves could be valuable in districts where there is insufficient information on the subject and thus only a single value which could be adjusted to the particular conditions prevailing in the new zone would be necessary.

An alternative to averaging the estimated water use for each crop as suggested by the authors would be to weigh the respective values according to the amount of each crop in a district. This may be important where there are wide variations in consumptive use, such as for an early maturing crop that has a negligible requirement shortly after midseason. In northern climates, most crops are planted in the spring and approach peak water use simultaneously. These peak rates are nearly the same for all crops and frequently coincide with the most critical stage of plant growth. Under these conditions, a shallow rooted crop may require irrigations weekly, whereas a deep rooted crop may require irrigations only every 10 to 14 days making single level, single frequency irrigation impractical. If the frequency is established for the deep rooted crops, yield potentials can seldom be obtained on the shallow rooted crops.

REPORT 7 : **Irrigation planning for strawberry cultivation at Irrigation District No. 24, "Ciénaga de Chapala"—by Jaime Delgadillo Vasquez (Mexico)**

This report describes an irrigation study conducted in the northwest region of Michoacán State, Mexico. The objective of the study was to develop improved practices for the production of strawberries. The report contains a good general description of the area, general climate, precipitation, temperature, relative humidity, day length, evaporation (the type of pan was not specified), wind and cloudiness. About 71 per cent of the soils are clay, and have low permeability, especially in those areas that have some exchangeable sodium. The soil depth ranges from 0.2 to 2.5 m and is limited by a clay hardpan high in soluble salts. The farming area is a former lake, dried by protective embankments and drained by pumping. The water table is near the surface and portions of the lower part of the district are affected by soluble salts. The average slopes are about 0.5 per cent. Strawberries have been grown in the adjacent Zamora Valley for many years using practices that have been damaging to the soil. This study was conducted during the 1966-67 season on one hectare of land to establish improved irrigation practices for District 24. The irrigations were based on gravimetric soil samples. The water used was mildly saline. A datailed description of plot preparation, climatic instrumentation, and the method of irrigation (parallel furrows having a uniform depth of 20 cm, spaced one meter with a 60 cm furrow shoulder) is provided. The land was levelled to permit a furrow slope of 0.1 per cent in the direction of irrigation. Soil samples were taken by 15 cm layers to a depth of 45 cm. Detailed physical and cultural practices are described along with irrigation dates, net water applied and net rainfall.

The usual watering interval in the Zamora Valley varies from 3 to 6 days and in this study the average interval without rainfall was 10.6 days which reduces to an equivalent of 9.2 days when considering rainfall. A total of 24 irrigations, each applying 85 to 100 mm was given during the 15-month period from August 1 to October 30. The total production of strawberries was 20 tons per ha. The total volume of water applied was 20,000 m^3, resulting in a production of 1 kg of strawberries per m^3 of water. The author indicates a water saving of 50 per cent as compared to the amount used in the Zamora valley for a similar crop. The production per unit volume of water in this case refers to the volume of water applied and not the volume of water used consumptively.

REPORT 8 : **Estimate of consumptive use of water based on evaporation data in a "Class A" evaporation pan—by Enrique Palacios Velez (Mexico)**

This paper describes the results of several years' of research conducted at Irrigation District Number 38 by the Irrigation and Drainage Officesi n northwest Mexico. The objectives of the study were to develop a practical method for estimating water consumption of crops based on evaporation data obtained with "Class A" evaporation pans used by the Mexician Meteorological Service.

Coefficients, K, were developed for use in the equation $E_p = KE_v$, where E_v=evaporation. The coefficients developed were based on the assumption that the irrigation intervals and soil moisture levels were adequate for optimum economic production and that water use under these conditions could be considered optimum evapotranspiration.

Evapotranspiration was determined using the gravimetric soil sampling method, sampling to a depth of 80 cm and in some cases 120 cm. The results are presented graphically with K as the ordinate and the percentage of the crop growing season as the abscissa. Equations for the coefficients require polynominals up to the 6th degree and these were included for one example crop. Figures 2 to 10 present values of K for sorghum planted March 20 and June 12, winter wheat, winter linseed (flax), spring cotton, winter safflower, along with general curves for winter spring and summer crops. Values of K for sorghum reached a maximum of 0.6 for spring sorghum, 0.81 for summer sorghum, 0.72 for winter wheat, 0.61 for winter flax, 0.60 for spring cotton, and 0.75 for winter safflower. The maximum coefficient for winter crops was 0.66, for spring crops 0.54 and for summer crops 0.85. An example is given illustrating the use of these coefficients in estimating evapotranspiration for a given crop throughout the season.

The values of the coefficients and the variation with stage of growth are similar to those obtained by other investigators. They illustrate that for maximum utilization of water resources and high yields in semiarid areas, equal depth—equal interval irrigation is not compatible with evapotranspiration.

REPORT 9: **Problems of determining irrigation water requirements—by G. Manuellan, J.L. Dervil and J. Khobzi (France)**

In this report, the authors review the principles of water requirements of crops with particular emphasis on potential and real evapotranspiration (E_{tp} and E_t), the factors controlling potential E_t, such as the requirement that a crop has attained a leaf-area-index of 2.0 or more, the limitations of potential E_t formulas, root-soil and leaf resistances to water or vapour movement, crop coefficients relating E_t to E_{tp}, and the desirability of standardized experimental design on an international scale.

The Technical Division of the Hydraulics Bureau of the Ministry of Agriculture has published annual, seasonal, and monthly deficits on a frequency basis for 150 stations in France. With these data and soil-climate maps, estimates of supplemental water needs are easily derived. However, precise applications of these estimates to individual fields is often greatly complicated because many factors must be considered. Bulletins are distributed to farmers periodically giving theoretical changes in soil moisture for the preceding week or 10 days along with a forecast for the next few days. The farmer must apply various coefficients to represent the influence of crop growth stage and soils.

A model for evaluating the influence of the total and annual distribution of water supplied on crop yields is described in detail. Examples describing how this model can be used in determining the economic aspects of irrigation on a farm and national basis are also presented.

REPORT 10: The water requirements of grass—by Edward T. Linacre (Australia)

In this report the author presents an excellent detailed analysis of measured evaporation from well-watered grass in relation to evaporation from a pan and estimated lake evaportion. Published data from Belgium, Canada, Denmark, the States of New York, Connecticut, California, Colorado, Alabama, Florida, Hawaii (USA), Australia, Israel, Nigeria, and Tunis were used to derive ratios of evapotranspiration to evaporation and estimated lake evaporation. A similar analysis was made using data from Holland, England, Belgium, Canada, France, New Zealand, California and North Carolina (USA), Israel, Australia, and Nigeria and estimates of lake evaporation obtained with the Penman equation. The results from this analysis indicated that the ratio E_t/E_o (evapotranspiration to estimated lake evaporation averaged approximately 1.2 with no clear separation of summer values) from the whole year values (summer 1.23, and winter 1.17). When the rate of lake evaporation was estimated from the Penman (1948) equation, the ratio was about 0.8 with a mean summer value of 0.76. The difference in the ratios implies that the Penman equation gives estimates of lake evaporation that are much higher than that estimated from pan parameters. The ratio of lake evaporation estimated by pans compared to estimates by the Penman equation is about 0.67 which is a pan factor for the Class A pan. These data suggest that Penman's formula tends to equal those measured by a pan rather than by a lake corroborating similar observations given by Kohler (1958) and Chapas and Rees (1964).

All of the grasses studied generally showed similar relationships with the exception of the kikuyu grass which tended to have a much lower ratio. One reason which accounts for part of the lower evaporation rate from the kikuyu grass is its higher albedo, 0.30 *versus* 0.25. On the average, the net radiation received by ryegrass at Griffith, Australia was 1.14 times that absorbed by the kikuyu grass.

A detailed summary of daily E_t data for grass at Griffith, New South Wales, Australia is presented in this report along with temperature, relative humidity, windspeed, and hours of sunshine per day for the ryegrass and the kikuyu grass. In addition to presenting an excellent summary of the relationship of E_t for grass to evaporation measured by an evaporimeter, the author illustrates the importance of pan environment on evaporation. He cites data by Pruitt (1960) which indicates that a factor of 0.7 for a pan on dry ground rises to about 0.9 if the pan is surrounded by a well-watered cover crop. Similarly, he refers to Hounam (1958) which showed that the annual ratio was 0.86 for a pan at Griffith and 0.97 in the wetter part of Australia. A major conclusion implied by the results of this and other reports is that the relationship between evapotranspiration to evaporation from a pan is not necessarily a constant at a given stage of growth because of several key factors: (1) Evaporation from a pan is dependent on its immediate environment as well as the size of the pan, and (2) evaporation from a pan and evapotranspiration from a crop do not necessarily respond proportionately to varying environmental conditions, especially where advection plays a significant role in the energy required for evaporation.

REPORT 11 : **Need of irrigation water for sugar cane plantations in Mexico—by Alfonso Gonzalez Gallardo and B. Ortiz Villanueva (Mexico)**

This report summarizes the magnitude of sugar cane production and sugar manufacturing in Mexico under both irrigated and dryland farming conditions, the water requirements of sugar cane, and the method used in planning irrigation. The authors believe that production potential is not being attained through lack of utilization of available sources of water which are still available in the sugar cane area. In other areas excessive irrigation water is being used.

Annual precipitation, and average annual maximum, absolute maximum, minimum and absolute minimum temperatures are presented for the various regions producing sugar cane in Mexico. The necessary water consumption for sugar cane varies with each region and ranges from 3.8 to 8.6 mm per day in temperate-hot climates and from 4.8 to 8.9 mm per day in hot climates. The report contains a review of sugar cane irrigation experiments in Formosa, South Africa, Haiti and India.

The method used in the irrigation program, considering such factors as water retention capacity of the soil, evapotranspiration, rainfall, temperatures and humidity, is summarized. The authors estimate that when the foliage covers one-fourth of the area, sugar cane uses only 50 per cent of the daily consumption of the adult plant. When it covers 50 per cent consumption is equal to 75 per cent and when it has covered more than 75 per cent it is equal to consumption at full cover. With these assumptions, estimates of evapotranspiration range from 1,812 mm to 1,955 mm. Only 71 per cent of the average monthly precipitation is assumed to be effective. Water losses in distribution to the field vary from 40 to 60 per cent. Using these and other criteria, the water requirements and water surpluses in sugar cane production regions in Mexico are presented graphically and in tables.

A summary of the guides utilized in irrigation by furrows and at different gradients is presented indicating that 150-200 mm of water is applied per irrigation, and that rainfall of 75 mm during a two-week period is equivalent to a turn. The irrigation interval is dependent on soil moisture depletion. They allow depletion to 66 per cent of the available water during the first three months, 50 per cent during the second three months, and 35 per cent during the third three month period. Before harvesting sugar cane, a period of one to three months without irrigation is allowed.

Experiments conducted from 1957 to 1960, comparing sprinkler irrigation with surface irrigation, showed no improvement in yields at the field or factory levels. However, the sprinkler irrigation method is suggested when water is scarce or limited, on irregular topography where surface gravity irrigation or pumping is difficult and expensive, and on very permeable soils. They indicate that the most convenient and economical depth of water application with a sprinkler system is 65 mm *versus* 150 mm for surface irrigation on clay soil and 480 mm on a gravel soil resulting in 710 mm applied with sprinkler irrigation *versus* 1,830 mm applied on clay and 5,310 on gravel soils.

REPORT 12: **Survey of research on water consumption in plant production in Poland—by Cz. Somorowski and St. Marcilonek (Poland)**

Supplemental irrigations are necessary for intensive agriculture in Poland. This report summarizes research on water consumption without irrigation from which irrigation water demands have been computed using a water balance equation. The report contains a general summary of the climate, which is influenced by maritime conditions from the west and continental conditions from the East (mean annual preciptation, mean air temperature, and the sum of mean daily saturation deficits). The soils in Poland were developed under the influence of glacial action and nearly one-half of the territory is covered by sandy formations; consequently, rainless periods of 9 days or more at critical stages of growth from April through July may be particularly harmful. The authors assume that soil moisture must lie within the interval from 65 to 100 per cent of field capacity to enable an undisturbed water supply for plant growth. A summary of permissible soil moisture deficits on this basis is presented along with a summary of yields and seasonal evapotranspiration coefficients for summer barley, winter wheat, potatoes and sugar beets.

Investigations of water requirements were carried out using lysimeters, field studies, and small river basins. Extensive lysimeter investigations using stationary and movable weighing lysimeters with ground-water levels maintained within specific intervals, depending on the soil and crop, have been conducted since 1946. From these studies, Ostrcmecki developed an empirical formula relating evapotranspiration from the lysimeter to ground water depth, crop yield, the sum of daily air moisture saturation deficits, and experimental coefficients that depend on the soil and crop.

Field investigations have been carried out since 1948 using gravimetric soil moisture determinations to a depth of one meter. References to the results of this work are cited. The crops involved are winter wheat, summer barley, potatoes and sugar beets.

River basin investigations have been carried on in Poland for quite some time, but were modified in 1956 using two small lowland river basins. The usual watershed parameters were measured in addition to soil moisture which was determined monthly. The mean evapotranspiration from April to October, from 1956 to 1964, was 432 mm in the Tuczna river basin and 463 mm in the Osowinica river basin. A comparison of hydrometric coefficients (the sum of evapotranspiration divided by the sum of vapour pressure deficits) is presented for summer wheat and potatoes in lysimeters, winter wheat, summer barley, potatoes, and all rotations in fields and in the two river basins.

REPORT 13: The reaction of annual plants to irrigation in the different growth stage—by H. Bauman (Federal Republic of Germany)

In this report the author discusses the effects of water supply and the resulting reactions of plants. He emphasizes that many experiments in which soil moisture has been depleted to specific degrees show that very frequently irrigations were necessary—especially on sandy soil. However, it was not always possible to determine a clear correlation between yield and amount of water actually applied (supplemental irrigations).

The author describes the general water requirements of plants at different stages of growth in order to attain high yields. A summary of a compilation of 1200 books and papers on this subject by Salter and Goode is included in the appendix to this report.

The author analyzed good and poor yields obtained in different years in Germany in relation to rainfall and its distribution throughout the season. From this study he presents conclusions concerning the sensitivity of various crops to rainfall in early spring, lack of rainfall in August and heavy rainfall in the fall.

In regards to the difficulty encountered in obtaining a simple relationship between water application and production, the author indicates that the ratio between evapotranspiration and evaporation is not constant. The ratio tends to be larger in cool years than in warm years. (The type of pan involved was not given, but a significant portion of this effect can be due to the disposition of net radiation into latent and sensible heat for a crop in comparison to an evaporation pan as discussed in Report 10. The author indicates that a premature application of water results in higher applications being required at later stages. A sprinkler experiment conducted in 1962 and 1964, for example, is cited from which the author concludes that sprinkler irrigation during July also means that heavy applications during August will be necessary due to the condition of the plants.

Sprinkler irrigation studies carried out on a loamy sand near Berlin showed that sprinkler irrigations during the second half of the growing period was more effective than during the first half of the period. In another experiment conducted in 1954, an irrigation just prior to a minimum temperature of4.—5° C reduced the yield of oats 10 dz per ha when compared to the unirrigated plots. The damage was attributed to a higher water content in the plants. Other examples of a supplemental irrigation prior to either a warm period or a cool period and its effect on growth are discussed. The author cites the increase in humidity and reduction of air temperature in vineyards due to sprinkling during midday hours in Germany, which increases the yield of grapes and quality of wines, as an example of climatization.

REPORT 14: Limitations of the intensity of evapotranspiration in extremely different climatic zones—by U. Schendel (Federal Republic of Germany)

In this report the author discusses the differences between the cool-temperate climates and warm-temperate subtropical climates and their effects on evapotranspiration. A table is presented summarizing rainfall, runoff, and evapotranspiration in the different climatic zones which merely indicates that evapotranspiration (without supplemental irrigation) is the difference between rainfall and runoff even though the E_t potential may be considerably higher in warm climate as compared to the cool climate zones. Thus he concludes that actual evapotranspiration is not a suitable characteristic of climate or a measure of the actual water requirements of plants.

The author also discusses the influence of decreasing soil moisture on evapotranspiration and indicates that the degree of availability is related to the amount of soil moisture only when E_t is constantly high or decreasing. Data are cited showing a significant decrease in evapotranspiration as temperature and soil moisture decrease. However, the magnitude of E_t immediately after irrigating (12 mm per day) indicates that some drainage may have occurred simultaneously. The reduction in evapotranspiration from 12 mm per day to 1 mm per day in five days with a corresponding decrease in temperature from about 25° C to 20 during the same period also indicates that the depth of soil sampling may not have been adequate, or only a partial plant canopy may have been involved. No information on net radiation during this interval, the degree of plant cover, or the depth of soil sampling was provided. A second example is given where the temperature and E_t increase for three days after an irrigation and then decrease to 1 mm in 5 days.

A summary of mean daily E_t for several crops with available soil moisture between 30 and 60 per cent is presented showing only small differences in the rates between the two climatic zones with air temperatures of about 21° C in Germany and 28°C in South Africa. The similarity of the mean daily E_t rates of about 5 mm per day is attributed to the capability of plants to reduce their transpiration under conditions of increasing moisture stress. This reporter believes that the similarity between the two data could largely be attributed to similarity in net radiation and not due to a reduction in transpiration on the part of the plant within the available soil moisture range specified. The author attributes the higher total water consumption in warmer zones primarily to a longer duration of the growing period. In summary, the author indicates that maximum yield per unit of water can be obtained by establishing cover as rapidly as possible and that the utilization of narrower spacing and increased fertilization are means to achieve this objective.

REPORT 15 : **Results of investigations on sprinkling irrgation of crops at different mineral fertilization rates—by J. Dzlezyc (Poland)**

This report summarizes the results of experiments carried out from 1962 to 1967 on light and medium textured alluvial soils in the vicinity of Wroclaw, Poland to determine the effects of irrigation and high fertilizer rates on crop growth, quality and quantity of yields, and water consumption. In this area the mean precipitation from April to October is 340 mm and the mean air temperature is 14.2° C. The experiment was carried out using randomized blocks replicated 3-4 times. Irrigations were timed by considering stage of growth, precipitation, and soil moisture. Control NPK rates for root crops and vegetables on manured land was 150-200 kg per ha; for cereals and oil crops, 90-130 kg per ha ; and for fodder crops, 70-170 kg per ha. Other rates of fertilizer applications were 2, 4 and 6 times these rates.

A summary of the control yields for sugar beets, fodder beets, fodder carrots, early potatoes, winter wheat, summer wheat, oats, red clover and alfalfa are presented along with the yield increases due to the various treatments. The increases in yield were not always accompanied by similar increases in quality. For example, the sugar percentage of beets decreased 1-1.5 per cent, starch percentage in potatoes decreased 1 per cent and protein in cereals decreased 1-1.5 per cent. Harvest time was frequently retarded due to high moisture content in the grain and straw. As a general rule, yields were much higher on fields irrigated and fertilized.

Irrigation-fertilizer interactions on winter wheat, potatoes and sugar beets are also summarized. The greatest response to irrigation on sugar beets occurred during the period of root thickening after full vegetative cover had been obtained ; on potatoes, at the flowering and tuber forming stages ; on legumes, during the flower, bud forming and flowering stage ; and on cereals, from heading until the milk stage. Winter wheat showed a response to irrigation during boot stage. The author reports an increase in water consumption with additional increments of fertilizer. However, yields increased proportionately more resulting in a 10-15 per cent greater water use efficiency (production /per unit volume of water) where fertilizer was used. The summary of the P_2O_5 and K_2O in the soil before and after the four-year experiments indicated a decrease in these values under sprinkler irrigation.

A graph summarizing the relationship of the difference between potential evapotranspiration and precipitation, and yield indicates that maximum yields were obtained where the differences were within ± 50 mm, but at differences of about ± 100 mm, a yield decrease was observed. The author concludes that utilization of high fertilization rates is not possible without supplemental irrigations.

REPORT 16 : **Behaviour of sorgo (Sorghum Vulgare L) under four humidity regimes—by Jaime Leal Diez and Juan Donald Vega (Mexico)**

This report summarizes the results of an experiment conducted at the Technical and Higher Studies Institute of Monterrey, Mexico during the period March 10 to June 15, 1967. Four irrigation treatments were used on hybrid grain sorghum. The treatments involved irrigating when the available moisture in the root zone decreased to approximately 20, 40, 60 and 80 per cent. The available soil moisture was determined as the difference between the water in the soil two days after irrigation and the water at permanent wilting. Consumptive use was determined by gravimetric soil sampling at 15-cm intervals to a depth of 90 cm. An excellent summary of soil moisture characteristics is presented.

The authors introduce a term "non-accessible available water". This term is defined as the difference in soil water content in the first 15 cm of depth measured under a heavily watered plot which was covered with plastic for eight days, and the water content in a similar heavily watered plot which was not covered with plastic. Consumptive use, consumptive use less non-accessible available water, and the number of irrigations for each treatment are summarized along with grain production, foliage weights of parent plants and shoots, and plant height. Grain production was the highest on the high moisture level. Because of the shoot growth that occurs as the main crop is maturing, the amount of water used from this period until harvest was deducted from the total evapotranspiration (including non-accessible available water) to estimate the amount actually used by the parent plant. After making these corrections, the relationship between grain and foliage production and the corrected consumptive use appeared to be linear. This relationship did not hold when excluding the non-accessible available water. The authors also evaluated the relationship between grain and foliage production and water extraction by various layers, *i.e.*, from 0-10, 0-20 cm, etc. These evaluations indicated a higher correlation between the water extraction from the shallowest layer as compared to the total. They attributed this to the fact that the highest irrigation treatment extracted more water from the most fertile strata of the soil, and therefore, produced the most dry matter. These results were evaluated by tests in a greenhouse where plants were grown in soil taken from the various depth increments. Significantly different productions from each of the soil layers was obtained.

The authors indicate that the same amount of water was used in each case to produce a ton of green or dry matter except when they subtracted the non-accessible available water. Then the highest water treatment produced more grain per unit volume of water. Soil moisture extraction patterns are included as well as *k* values for the Blaney-Criddle equation for each 10 days of the growth cycle.

REPORT 17 : Irrigation requirements of perennial pasture in Southern Victoria, Australea—by L.F. Bartels (Australia)

This report summarizes a four-year study on consumptive use of pasture on claypan soils. Earlier experiments indicated that the highest yields were obtained when 600 mm of irrigation water was applied to supplement the average annual rainfall of 500 mm, and that the irrigation water was best applied in 100-mm increments. However, it was soon found that 100-mm irrigations were impractical on a farm scale because the red claypan soils could seldom absorb this quantity of water in a single application. Studies in the 1930's indicated that lighter, more frequent irrigations produced as much pasture as the infrequent heavier irrigations without increasing the duty of water beyond 600 mm, and fertilization at a rate of 5 quintals per ha of superphosphate resulted in greater water use efficiency.

The earlier studies were largely agronomic in nature with no attention paid to the soil moisture status. This experiment involved irrigations controlled by gypsum blocks buried in the top soil. A water balance equation which involved the soil moisture content, runoff and drainage was used to calculate evapotranspiration. The experiment was replicated three times and four treatments were used. Each treatment was contained in a small border check, 80 m by 13 m, which was irrigated when soil suctions reached 1, 3, 8 and 13 atms (wet, moist, semi-dry and dry regimes). Five quintals of superphosphate per ha per year was applied. Water was measured by pumping both the inflow and the drainage from each plot through meters. Soil moisture storage and depletion were determined by sampling just before and one day after irrigation. Standard meteorological observations were made at 9 a.m. in a weather enclosure near the experimental site. The plots were surrounded by a minimum of 100 m of irrigated pasture. Evaporation was measured by a standard Australian tank evaporimeter and rainfall was measured by a standard 20-cm diameter rain gage. A detailed summary of the number of irrigations, total intake, mean intake, and dry matter yield is presented.

The author found an excellent relationship between the total intake and water storage one day after an irrigation, and the water storage just prior to an irrigation. From these data, an empirical equation was developed for estimating the seepage loss as a function of soil moisture prior to irrigation, rainfall and evaporation. The author indicated that although some seepage losses were possible from the wet plots on the second day, the greatest part of the loss from all of the other plots is completed within 24 hours.

The average rates of E_t for the three seasons are presented graphically and the various components of the water balance equation for individual sampling periods are presented in tabular form.

The pasture yields were the greatest at the highest moisture level. The drainage following an irrigation displays a seasonal variation, being greater in the spring and autumn than in the summer because E_t draws on loosely held water first that would otherwise drain away. These results indicate that the probability of significant drainage errors entering into E_t determinations is considerably greater in the spring and autumn when E_t rates are lower. Higher drainage in the spring and fall is one of the reasons why many experiments tend to show similar rates of E_t throughout the season. It also indicates that a correction for drainage that is constant is not valid.

The author also found that the ratio of evapotranspiration to estimated evaporation by the Penman equation averaged 0.9 and that this relationship could be used to estimate the net irrigation requirements for pasture throughout the state of Victoria. However, the author recommends direct measurements of consumptive use at each of the major irrigation centers. Work towards this objective is currently underway.

REPORT 18: **Water use by wheat in the steppe regions of the U.S S.R. European part—by O.G. Grammaticati (U.S.S.R.)**

This report summarizes the results of a study of evapotranspiration of wheat in the steppe regions of the European part of the USSR where average rainfall is insufficient for high constant yields without irrigation. A general description of the climate, including rainfall, length of growing season, the number of days, the mean air temperature is above 10° C, maximum air temperatures, relative humidity, and the number of dry, windless days, is presented. In general, with less than normal winter precipitation, the soil moisture stored at the beginning of spring plant growth is not sufficient for normal plant growth and maturity. In the droughty area, the main objective of spring and winter wheat irrigation is deep, off-season autumn irrigation thereby producing favourable moisture conditions for plant growth and development during the entire vegetative season. Evaporation loss from the soils in this area takes place primarily from the first 70-80 cm depth; therefore, water storage in deeper layers is not lost by evaporation but is utilized by the plant. The available water in the soils at field capacity is about 180 mm in the first meter and close to 360 mm in the 0-2 m depth.

A summary of soil moisture depletion and total water content in the soil for different periods of the growing season is presented. In the spring of the year, the rate of water use is between 1.5 and 2 mm per day. E_t reaches a maximum of 6 to 9 mm per day between the booting and pre-yearly seed stage and on certain days may exceed 10 mm yer day. After that, E_t decreases, and during the final stages of plant development is 2 to 3 mm per day.

A summary of water use for the period April 25—August 5, without irrigation, with off-season irrigation, and with off-season irrigation plus seasonal irrigations is presented. With off-season irrigation, one irrigation may be eliminated during the season without reducing spring wheat yields. Yields of spring and winter wheat are summarized for the various irrigation treatments. The maximum yield of 58.4 centners per ha was obtained when deep, off-season autumn irrigation and four seasonal irrigations had been applied to winter wheat resulting in a total irrigation application of 444 mm. Winter wheat yields are greater than spring wheat yields.

Other studies on winter wheat water use by the author indicated extraction of water takes place from the entire 0-300 cm depth, and that when calculating water use for a deep rooted crop, such as winter wheat, significant errors can result if less than the full profile is considered.

REPORT 19: **Use of so-called summation method to determine sum of transpiration from plants each day and during growth season —by Miroslav Penkat (Czechoslovakia)**

This report discusses a summation technique to determine transpiration from a given plant by excising portions of the plant. The rate of transpiration from the excised portion is measured gravimetrically over a three minute period and is assumed to be the same as the rate existing just prior to its separation from the main plant. These measurements are made at 08.00, 11.00, 14.00 and 17.00 hours (a total of 8 values per plant). Under some conditions the amount of sampling can be reduced to a single day representing the average for the entire week.

Examples of the data collected in this manner in the field from May 6 through July 31 are presented in tabular form. A diagram illustrating cumulative growth and developmental stages throughout the growing season is presented along with graphic presentations of transpiration during the day and night. Two types of curves are illustrated—one showing a single peak during the day and another showing a depression during mid-day with a peak prior to and after the depression. These studies indicate the highest sum of transpiration occurs during the development stage of rapid growth (or stem extension) up to flowering although all three stages of stem extension, flower formation and flowering represent periods when soil moisture content decreases rapidly. The author also reports that transpiration may occur without replenishment from soil moisture, especially near the end of flower formation and flowering. Summer wheat, with approximately equal yields of straw and grain, had a lower sum of transpiration than winter wheat varieties. The author indicates that the same sums of transpiration in plants need not necessarily result in equal levels of crop yields. In addition, a given soil moisture level may induce physiological and morphological changes in one variety that is different from another variety.

REPORT 20: **Water needs of maize—by Miloslav Pycha (Czechoslovakia)**

This report summarizes a study of water nee s of maize conducted in Czechoslovakia from 1955 to 1963 using gravimetric soil sampling procedures. The soils were sampled by 5 and 10 cm increments to a depth of 1 m once a week, 24—36 hours before and after an irrigation, and after precipitation exceeding 120 mm in 24 hours. Three moisture treatments were used, one non-irrigated and the others irrigated when the available soil moisture reached 75 and 50 per cent, respectively. Each moisture treatment was further subdivided into two parts which were fertilized at different rates. Field capacity and wilting point values for the soils were determined in the experimental area. Deep percolation, considered as the difference between the water content measured after irrigation and field capacity, was evaluated when the measured water content was greater than field capacity. Biological coefficients, which are the ratios of water consumption to the sum of daily saturation deficits, were determined for time intervals corresponding to the sum of average daily air temperatures totaling 200° C. A detailed description of the soil is presented along with normal precipitation and temperature on a monthly basis. A summary of the beginning and duration of the vegetative period, average temperature, precipitation, relative humidity, saturation deficit, sunshine hours, cloudiness, and wind velocity is presented along with total consumptive use for each of the eight years on the irrigated and non-irrigated plots.

The average yield with the non-irrigated plots was 4,517 kilos per ha. The yields on the irrigated plots were 5,348 and 5,740 kilos per ha for the 70 and 50 per cent available moisture plots, respectively. A summary of water needs in mm and saturation deficits in mm Hg for the season was presented along with a linear equation relating water needs in mm to the saturation deficit in mm. The vegetative period was not the same each year, and did not begin and end at the same time during the year within several weeks.

The water needs of the crop was related to both crop development and meteorological parameters. In order to eliminate the influence of the difference in length of the growing period in each year, air temperature was used as one of the basic factors influencing the development of the crop. The vegetative period was divided into equal increments corresponding to 200°C sums of daily air temperatures for which biological coefficients were derived and presented in tabular form. These caefficients began at 0.37, increased to 0.74, and then decreased to 0.57 at harvest. With these coefficients the author proposes the use of the equation, $ET_p = k_b\ (S_d)$, for estimating water needs for any period. The author hopes to have similar curves for 10 basic crops available by 1975 for which irrigation is planned in Czechoslovakia.

REPORT 21 : Field investigation of crop water requirements in Syria—by G.J. Koopman, C.H. Swan, and J.M. van Gessel (Great Britain)

This report summarizes studies of crop water requirements of cotton and alfalfa at two locations in the semiarid region of Syria in 1965, 1966, and 1967. A general description of the area, the soils, water table and salinity conditions are presented along with a summary of climate by months including rainfall, mean temperature, relative humidity, per cent sunshine, windspeed at 2 m, and evaporation. A summary of available moisture in the 0-60 and 0-80 or 100 cm depth is provided. Characteristics of the soils were determined on undisturbed and disturbed samples at the Institute for land and Water Management Research at Wageningen, Holland. A review of literature for both cotton and alfalfa is presented. The review indicated a rapid increase in water consumption by cotton with the appearance of the first flower ; for example, the coefficient relating evapotranspiration to the estimate by Penman's equation would increase from 0.4 or 0.5 prior to flowering to values exceeding 1.0 during flowering and occasionally reaching values as high as 1.5 for short periods.

The 50-m long cotton plots were graded to a slope of 0.2 to 0.3 per cent and were irrigated by furrows. Phosphate and ammonium sulphate were applied at rates of 250 kg per ha in 1965 and 1966, and 600 kg per ha in 1967. Alfalfa was grown in similar borders having a width of 10 m and fertilized at a rate of 500 kg of superphosphate per ha and 100 kg of ammonium sulphate per ha. Nitrogen was supplied to compensate for a lack of N-fixing bacteria in the soil which had never been planted to leguminous crops. Parshall flumes were used to measure the inflow and V-notches were used to measure outflow from these plots. The V-notches were replaced by Parshall flumes in 1967. All of the plots were sampled for soil moisture at least once every three days.

Cotton irrigations were scheduled on a basis of estimated E_t in 1965 without soil sampling. The crop factors, used in 1965 to estimate consumptive use, were 0.4 for April and 0.6 for May through September inclusive with irrigation intervals of 9, 12, 15, and 18 days for the four treatments. The crop factors were revised in 1966 and the treatments were revised in 1966 and 1967. In 1966 the crop coefficients used to estimate consumptive use were 0.4, 0.6, 0.75, 0.9, 0.6 for May, June, July, August, and September, respectively. Five different treatments were selected based on the total seasonal application. These were 0.6, 0.8, 1.0, 1.2, and 1.4 times the estimated seasonal consumptive use. Individual irrigations applied fixed amounts with the intervals between applications ascertained by the five treatments. In 1967 the treatments were modified to irrigations of 1.0, 1.2, 1.4, and 1.6 times the estimated seasonal consumptive use. In the treatments with the larger applications, some water was lost due to deep percolation. In another experiment, the effects of different moisture levels on consumptive use were evaluated. These plots were irrigated when 10, 30, and 50 per cent of the available moisture was left in the soil, and 30 per cent before flowering and 50 per cent after flowering. The amount of water applied at each irrigation was calculated to bring the soil to field capacity, the results from the 1966 and 1967 studies indicate that the highest yields were obtained when the amount of water applied ranged from 1 to 1.4 times the estimated consumptive use. A sudden increase in the crop coefficients was observed during the period of flowering when the crop was adequately supplied with moisture. Monthly crop factors for 1966-67 for both locations are presented in tabular form. Crop factors for 10-day periods are presented for test 2 in 1967 which indicates that the crop coefficient is about 0.4 in May, increases to about 1.0 in July and August, and then decreases to 0.3-0.4 in September.

The results from the alfalfa study indicate that evapotranspiration and evaporation from a free water svrface, calculated with the Penman equation, are very similar in April and May and from September through December. The alfalfa treatments were : (*a*) Irrigated from March to October inclusive with water being applied when 60 per cent available moisture was left ; (*b*) induced dormancy during July and August which is commonly carried out in the area to establish cleaner stands, to control insects and to avoid scalding by irrigation during the hottest part of the season ; (*c*) irrigated from March to October with water applied when 30 per cent available moisture was left ; (*d*) irrigated with induced dormancy during July and August, but otherwise when 30 per cent of the soil moisture was left. The highest yields were obtained when the alfalfa was not allowed to become dormant at either of the locations and where the plots were irrigated with 60 per cent of the moisture remaining, although there was not a great deal of difference between the 30 and the 60 per cent treatments. The ratio of evapotranspiration to E_o at the 30 per cent level ranged from 0.65 in the spring and autumn to 1.1 to 1.2 from July to September. The dormant plots made slightly more economical use of water.

No information was given on the environment surrounding the plots. The high rates of E_t (12-14 mm/day) indicates that advective energy was larger than normally encountered when plots are buffered by at least 50 to 70 m of irrigated land. This effect could be referred to as the "clothesline effect" discussed by Tanner in contrast to the oasis effect. Calculations for E_o also ranged from 11 to 12 mm per day. One other possible reason of the unusually high values of E_t and E_o at this location is that the windspeeds in June, July, and August ranged from 13.3 to 16.6 km per hour with average temperature of 28 to 30° C. The percentage of sunshine ranged from 91 to 95 per cent. Evaporation (type of pan not specified) ranged from 12.2 to 14.3 mm per day during the same period. Except for this question, this paper summarizes sufficient information in great detail along with supporting data to enable a thorough evaluation of the effects of treatments on yield in a semiarid climate. This report is one of the best presented on this subject.

REPORT 22: **Water requirements of crops as seen from the system çapacities standpoint—by Korkut Ozal (Turkey)**

This report reviews the various parameters affecting water requirements of crops, such as the heat energy supplied by solar and sky radiation, advected energy, and humidity. Empirical and theoretical methods of estimating evapotranspiration and the experimental methods of determining evapotranspiration are discussed. The various empirical methods cited are Lowry-Johnson, Blaney-Criddle, Turc, Hargreaves, and Thornthwaite. The Penman equation is indicated as providing the best agreement with actual data provided the Penman factors are determined with care. However, requirements for the Penman equation, which are the largest, are rarely available. A general discussion of factors involved in the water duty concept, such as crop irrigation water requirements, system losses, irrigation frequency and duration of application, and techniques for computing water duty is presented.

REPORT 23: **Water requirements of some field crops (wheat, sugar beets and alfalfa) at Western Central Anatolia, Turkey—by Dogan Dincer and Ozdemir Beyce (Turkey)**

This report summarizes the data on evapotranspiration determined by the Irrigation Research Institute of Turkey for three crops: wheat, sugar beets and alfalfa. The plots were located at the fields of Eskisehir Topraksu Research Institute. An excellent summary of climatic data for each of nine years is presented (average temperature. precipitation, relative humidity evaporation, and wind velocity at a height of 2 m above the soil surface). A description of the clay soils with field capacity and wilting percentages for the three sites are presented. The plots were 20 square m in size and the experimental design used was a 5 by 5 Latin square for wheat and sugar beets and a 4 by 4 design for alfalfa. No fertilizer was applied to wheat and alfalfa but superphosphate, ammonium sulphate and potassium sulphate were applied to sugar beets. Additional detail on seeding rates, method of irrigation, and the amount of irrigation water applied are also presented.

Five different irrigation treatments were used on the wheat and sugar beets, and four were used on alfalfa. The wheat treatments were: (*a*) check-no irrigation; (*b*) three irrigations-one after seeding the second after the stalking stage and the third at the beginning of the bloom stage; (*c*) three irrigations-preirrigation, the second at stalking stage, and the third at dough stage; (*d*) two irrigations-the first one after seeding and the second at the beginning of bloom stage; (*e*) one irrigation after seeding. Best results were obtained with three irrigations on treatments (*b*), (*c*) and (*d*) with the yield from treatment (*c*) being the highest.

The sugar beet treatments were: (*a*) irrigated at the depletion of 50 per cent available moisture; (*b*) irrigated as available moisture reached the wilting point; (*c*) irrigated when the leaves indicated wilting at 4 p.m. (*d*) first irrigation made as available moisture reached wilting point and during the rest of the season the moisture was kept close to field capacity; and (*e*) available moisture was held close to field capacity until the middle of the vegetative season and during the rest of the season, irrigated when the available moisture reached wilting point. The best yields were obtained from treatment (*c*) although treatment (*a*) was very similar and treatment (*b*) was only slightly less.

The alfalfa treatments were: (*a*) irrigated once following each cut; (*b*) irrigated once following each cut and again in two weeks; (*c*) irrigating once following each cut and again in two weeks after second and third cuts; and (*d*) irrigating at 40 per cent of available moisture in the 0-60 cm zone. There were no significant yield differences between treatments, although there was a significant decrease in the yield of alfalfa after the second year which was attributed to a lack of fertilization.

Detailed crop yields are presented in tabular form along with dates of water applications, amounts of irrigation water, effective rain and total moisture depletion in the 0-90 cm zone. Cumulative values of consumptive use are presented graphically for each crop. Mean monthly consumptive use values from these average curves are plotted against time for the vegetative season and are tabulated in tables. The peak value for sugar beets which occurs during the latter part of July and the first part of August, appears to be quite high (near 11 mm/day) when considering that the values for alfalfa are about 7 mm during the same period. Perhaps the method of computation may have some bearing on this. The values reported are classified as consumptive use (evapotranspiration plus undetectable seepage loss). One reason for the discrepancy between these two values is that sugar beets is a relatively shallow rooted crop and the water table was 1.5 m or more below the surface during the experimental period. Under these conditions, some use of water from the saturated zone by alfalfa would be possible during the peak period. Lysimeter studies are underway but data were not available for comparison.

This report presents a great deal of detail which could be analyzed more critically since a considerable amount of supporting data have been provided. It appears that the large difference in peak water use between sugar beets and alfalfa can be attributed to drainage taking place with sugar beets and in contrast possibly, some use of water from the saturated zone with alfolfa.

REPORT 24 : **Variations in consumptive use of wheat—an experimental study—by S.N. Gupta and A.P. Bhattacharya (India)**

This report summarizes the results of a study on consumptive use of water by winter wheat conducted from 1964-65 to 1966-67. This experimental site (a 1.65 ha field) was on the Government Agriculture Farm near Roorkee. A detailed description of the soils (mechanical and chemical) is provided along with a general summary of climatic conditions, growing season, and method of irrigation. A detailed summary of monthly climatic data for the period of study is also presented (temperature, humidity, evaporation, rainfall and per cent of sunshine).

The experiment consisted of one treatment in which the available soil moisture in the 0-1 m depth was depleted to specific levels before irrigation, a treatment where irrigations were given at different stages of growth, and a fixed depth and interval treatment. Nitrogen was applied at a rate of 67 kg per ha with one-half applied before seeding and the remaining half 30 days after seeding. Phosphorus (P_2O_5) was applied at 30 kg per ha before seeding. Other cultural practices are described in detail along with a typical example of soil moisture measurements.

Only one years' yield data were presented (1965-66). The best yield, 31.0 quintals per ha, was obtained on the soil moisture deficit treatment. The total water use was 334 mm, including 45 mm of rainfall, and 5 irrigations were given. The treatment in which irrigations were given at jointing, boot, flowering and grain filling (4 irrigations) yielded 30 quintals per ha. The fixed depth and interval treatment yielded only 22 quintals per ha. However, only two irrigations were given on this treatment, but these were given according to the usual practice in northern India (two irrigations completed by mid-February).

Seasonal and monthly consumptive use are presented for all three years. Peak rates of E_t were 3.5. to 4.0 mm per day in March. Seasonal

E_t ranged from 262 to 311 mm and are compared with winter wheat data from other areas with similar growing seasons.

An example of using mean E_t rates and the soil moisture deficit approach to scheduling irrigations is presented which indicated that four irrigations would be needed (January 4, February 2, February 21, and March 9) if no effective rainfall occurred. Preliminary studies with a high-yielding Mexican wheat, Lerma Rojo, resulted in yields of 44 quintals per ha with 4 irrigations based on the soil moisture deficit approach ; 49 quintals per ha when irrigating at pretillering, tillering, jointing, heading and dough stages ; and 48 quintals per ha with 5 irrigations of 50 mm each spaced at 3-week intervals.

REPORT 25 : **Field evapotranspiration as affected by soil variability—by K.K. Krogman and E.H. Hobbs (Canada)**

This report summarizes yield and evapotranspiration data for cereal and forage crops at three semiarid locations in Western Canada as influenced by soil variability. The principal study area was at Vauxhall, Alberta with additional sites at Youngstown, Alberta, and Kimberley, British Columbia. A summary of precipitation, evaporation, and mean temperature for the three locations for the period May-September is presented along with heat units expressed as degree days above 6° C and the frost-free growing season for each location. The soils at each location are described in detail as are the experimental sites. The plots were about 0.01 ha in size and four levels of irrigation were used. The yield and evapotranspiration data reported in this paper were obtained from an irrigation treatment where the soil moisture was maintained above the 50 per cent available level. Consequently, the data represent potential evapotranspiration as accurately as the field-plot techniques permit.

A summary of annual evapotranspiration for wheat, oats, barley, grass and alfalfa are presented along with yields. One of the significant conclusions from this study is that the differences in evapotranspiration for forage crops between two locations were more closely related to the length of the growing season than to daily rate of evapotranspiration. The authors also found that as soil variability increased, yield variability increased, but there was little increase in the variability of evapotranspiration. Thus, the authors conclude that in plot experiments, soil variability, that may be reflected in crop yields, does not yield a corresponding variation in measured evapotranspiration. Plot-derived evapotranspiration data have been related to pan evaporation and have been used to schedule irrigations on a budget basis in southern Alberta for several years. These studies were made in an area where irrigation is currently not generally practiced, but where the establishment of districts is proposed. An examination of the data indicated that these data are sufficiently precise for initial requirements in planning and are also suitable for use in an irrigation scheduling program similar to that now employed in the vicinity of the Vauxhall site.

REPORT 26 : **Water requirements of crops—by Giuseppe Piolante and Attillio Capparelli (Italy)**

This report discusses the results of about 100 tests carried out between 1963 and 1967 in the southeastern area of the Po Valley. The authors indicated that because of climatic characteristics, the characteristics and settlement of the land, the position of the water table, and the agricultural features of the area, traditional climatic formulas could not be utilized. The soils in the area have a high clay content and the water table is very close to the surface in many areas. Also, because of the wide variation in precipitation and soil conditions, sprinkler irrigation with an irregular interval was adapted. A summary of climatic conditions in the area (precipitation from April through September and June through August, average wind speed, relative humidity, and average temperature) is presented. Annual precipitation ranges from under 400 mm to over 1,000 mm whereas summer precipitation, June-August, ranges from 30 mm to over 300 mm.

After much discussion on the various alternatives to study in the development of irrigation in the area, the major emphasis was placed on when to start watering, optimum individual and seasonal irrigations, and when to stop irrigation. The studies were carried out using a split-plot technique with four or six replications. Irrigations of corn or sorghum were made according to soil moisture as indicated by Bouyoucos blocks placed at 20 and 40 cm depths. The most complicated experiments, involving up to four variables and nine rates, were carried out at experiment stations and simpler tests were made at six other locations. These tests were made to agronomically determine the optimum depths of water to apply at individual irrigations as well as the optimum soil water content using corn and sugar beets as test crops. Individual irrigations varied from 25-35 mm up to 100-105 mm. The volume of water applied was measured by rain gages. Average wind speed, relative humidity, and temperature are summarized by 10-day periods for each of the years in which the studies were conducted. Details on the production of alfalfa, cutting dates, unit irrigations, seasonal irrigations, etc., are presented in the appendix along with similar data on maize and sugar beets.

The results of this study indicate that for alfalfa the scarcity of precipitation and irregular distribution were the main causes limiting production. Optimum production was obtained with 30-50 mm per application and a total of 90-200 mm added during the season. With sugar beets, individual irrigations of 30-60 mm and seasonal totals of 180-250 mm gave maximum yields. The authors also found that it was necessary to stop irrigations 20-25 days before harvest and that early waterings were essential. Like sugar beets, corn also required early irrigations and the highest water requirements appeared to coincide with blossoming. Individual irrigations of 30-50 mm and a seasonal total of 150 mm produced optimum yields. The maximum effects of irrigation and the highest water requirements were found on clay soils, especially if they were subject to cracking. A summary of the volume of water required to increase production by one kg of dry matter or grain is also presented. As for future research, the authors concluded that it would be desirable to evaluate the probability of climatic variations and the probable effects of irrigations at different stages of growth.

REPORT 27: **Experiments on long line furrow method for cotton irrigation —by Leopoldo de Parias (Spain)**

This report summarizes the results of irrigation experiments in which cotton was irrigated with long furrows and siphon tubes. A brief, general description of the climate and soils of the middle valley of Guadalquivir is presented along with a summary of the cultural practices used on cotton (variety, fertilizer, and seeding and harvest dates).

Most of the report describes the long furrow method of irrigation and the problems encountered in obtaining uniform irrigations. Some data on the amount of water applied are presented. Initially, problems of uniform water distribution throughout the length of the furrows were encountered. During the third year of the study, more uniform water distribution was obtained which was accompanied by more uniform growth of cotton. The cotton in the sandy areas generally showed a need for irrigation before the entire field needed water. Because of the higher intake rates during the first few irrigations, these received more water than the last irrigation. Irrigations were applied when 2/3 of the available water had been depleted except for the period from 15 days prior to flowering through fruiting. During the latter period, depletion to 50 per cent was recommended. The furrows on the light soil at La Granja were 260 m long. The furrows on the clay-loam soil at Cortijo Nuevo were 160 m long. A summary of the irrigations, labour, and water applied at these sites is presented in tabular form.

The gross water applied during July and August was 444 mm at La Granja (net estimted at 356 mm), and 367 mm (322 mm net) at Cortijo Nuevo. The net consumption of water was evaluated as 5.4 mm/day during this period. The normal net annual water requirement of cotton is estimated at 500 mm.

REPORT 28 : **Influence of the different irrigation methods on the biological and physiological changes of some crops—by Todor Matev (Bulgaria)**

This report briefly summarizes the results of studies conducted in Bulgaria from 1958 to 1967. The objectives of these studies were to determine which irrigation practices result in the greatest yield of irrigated crops. The research was conducted at the Maritza Truck Crop Institute in Plovdiv on soils of low moisture holding capacity (16.5—18 per cent). In this area, the heaviest precipitaion occurs in May and June, and there is practically no precipitation in July and August.

Experiments conducted from 1958 to 1962 indicated that sprinkler irrigation of spring peppers produced more yield than surface irrigation. Tomatoes should be sprinkled during the afternoon and evening. Sprinkling from 10.00 a.m. to noon reduced tomato yields in comparison to furrow irrigation. Sprinkler irrigation of peas during midday produced more yield than surface irrigation or evening sprinkler irrigation. No data were presented on the design of these experiments, the treatments used, or the amount of water used or applied.

A detailed study of furrow irrigation, sprinkling and subirrigation of tomatoes is briefly described. No information was given on the parameters used to determine when to irrigate, or on the amount of water applied. Root distribution and plant growth with these three methods of irrigation are summarized. The sprinkler plots produced heavier stems and more foliage, but the fruit yield was greater with surface irrigation. A detailed summary of surface soil temperature indicated lower temperatures with sprinkler irrigatiod. Other characteristics of the plants, such as cell sap, transpiration, vitamin C, sugar, etc., as affected by the three irrigation methods are presented.

A brief summary of the effect of sprinkler irrigation and surface irrigation on sugar beets and corn indicates that sprinkler irrigation produced greater yields. Again, no details were presented on the parameters considered in determining when to irrigate and how much water was applied.

REPORT 29: **Determination of water requirements of crops by the bio-climatic method, using the sum of temperatures—by I. Delibaltov, Chr. Christov, and Iv. Tzonev (Bulgaria)**

This report presents the results of a study relating cumulative evapotranspiration to a single factor characterizing climate (sum of average daily temperatures), and a coefficient characterizing a particular crop as well as differences in climate (also based on the sum of average daily temperature). Evapotranspiration data for maize, lucerne and vineyards are presented graphically along with the sum of E_t *versus* the sum of daily temperatures for wheat, corn, sugar beets, cotton, tobacco, orchards and silage corn. Equations are provided relating the crop-climate coefficients to temperature based on 140 crop-years of data.

An evaluation of this method of estimating water requirements is presented with resulting errors for various stages of crop growth generally less than 20 per cent, and up to 10 per cent for seasonal values. This type of evaluation, however, essentially indicates the ability of two average temperature-dependent parameters to represent the average observed water use in Bulgaria. The error would probabiy be even larger if estimates were made for a specific weekly or 10-day period in a given year. The authors are to be commended for clearly illustrating the limits of confidence that should be placed in equations for estimating water requirements that are based on temperatures alone.

REPORT 30: **Water requirement of crops—by D. Velev and G. Markov (Bulgaria)**

This report briefly summarizes the physiographic, climatic, and soil conditions of Bulgaria. Average annual precipitation is 672 mm, with more than half occurring during the vegetative period from April through September. A general review of factors affecting water requirements is presented along with a listing of various methods for determining evapotranspiration. A method for estimating water requirements using a crop coefficient and the sum of the average daily vapour pressure deficits, $E = R\,\Sigma D$, is discussed in detail (also see R. 12, and R. 20). Values for the biological coefficient, R, have been determined for corn, sunflower, cotton, sugar beet, lucerne, and vineyards. The range for each was summarized, but not in relation to crop growth stages.

The method used in Bulgaria to evaluate the amount of supplemental irrigation needed for the season is described. This method required estimates of water requirement for 10-day periods. A comparison of these estimates with experimental data for corn, cotton, sugar beets, lucerne, sunflowers, and after-harvest crops in average and dry years is presented.

The results of a study to determine the relation between yield and water use are summarized indicatingthat yields are decreased more in dry years than in humid years if supplemental water was reduced. Also, corn yields were decreased 29 to 36 per cent if watering was suppressed during earing and flowering as compared to 7 per cent during the milky stage.

In conclusion, the authors indicate that annual water requirements change very little—80 per cent in a humid year, 90 per cent in a medium year, and 100 per cent in a dry year. Also, they recommend the bioclimate method as the most appropriate method for determining water and irrigation requirements, and that more studies should be conducted to evaluate *R* under different climatic conditions, irrigation practices, effective precipitation, and the relationships between water and yields.

REPORT 31 : **Irrigation water use efficiency—by Maurice N. Langley and David C.N. Robb (USA)**

This report summarizes a detailed study being conducted by the U.S. Bureau of Reclamation on the use of water on federal irrigation projects so as to provide a quantative procedure for estimating evapotranspiration, effective precipitation, and irrigation system losses. Detailed measurements of water delivery, surface runoff, precipitation, soil moisture at the beginning and end of the season, and estimated consumptive use are combined to compute irrigation system losses and efficiencies on an individual field-crop-application basis in 18 study areas in Western United States. One of the parameters that is being determined in this study is the "losses". In this paper, the losses refer to water in excess of that required to replenish depleted soil moisture although it is recognized that in many instances much of excess water applied can be recovered for reuse and thus is not truly a "loss".

Analysis of data collected to date indicate that losses from the point of diversion to the field may range from a low of 25 per cent of net consumptive use to as high as 300 per cent of net consumptive use. Thus, if irrigation efficiency is defined as net consumptive use divided by water delivered, these losses represent a range in efficiency from 25 to 80 per cent. It is obvious that when computing irrigation water requirements, estimates of expected losses are often as important as estimates of consumptive use.

A detailed description of the procedures used in arriving at the results, the factors affecting efficiency, and a detailed example of a given situation illustrating the diposition of water applied to a field of sugar beets is presented. This example also includes a summary of irrigation efficiencies and consumptive use on a biweekly basis. An economic summary is also presented illustrating the possible gains to be reached by controlling not only the amount, but the time of irrigations.

A summary of practices currently used to schedule irrigations, such as the evaporation pan in the Columbia Basin, the use of tensiometers by fruit growers in the southern San Joaquin Valley of California, and the irrigation management program of the Salt River Project Water Users Association at

Phoenix, Arizona is presented. The economic gains of the water management program at Phoenix, Arizona are illustrated with an example. A similar summary of a program, developed for scheduling irrigations using estimates of evapotranspiration based on solar radiation and air temperature in southern Idaho, is also presented.

REPORT 32: **Development of evapotranspiration-crop yield functions for managing limited water supplies—by Ian Stewart and Robert M. Hagan (USA)**

This report summarizes a detailed analysis of yield and evapotranspiration as measured directly or as indicated by evaporation from a Class A pan. The objective of the study was to develop a functional relationship which will enable water supply allocation or water management. All alfalfa data were obtained from one and two-year old stands. All plots had available soil moisture above 35 per cent, adequate fertility, and harvesting was performed at bloom stage. From a generalized production function for alfalfa, information is summarized on relative water use efficiencies of different irrigation programs.

Four steps are inuolved in developing the production function: (1) Relating crop yield data to evaporation pan data, (2) relating evapotranspiration to pan data using field and lysimeter data, (3) combining steps one and two to relate E_t to yield; thereby, developing the desired function, and (4) translating the production function into a relative form for use in other years and at other locations. Ten years of data obtained from experiments conducted by the University of California from 1911-1914, 1937-1939 and 1962-1964 were used. Preliminary inspection of the data indicated that conditions resulting in high evaporation were detrimental to alfalfa production, a concept furthered by de Wit with specific reference to alfalfa. Some of the results obtained in this study are in direct contrast with those proposed by deWit and the authors offer an explanation for this contrast. However, in the explanation, transpiration was calculated on the basis of the area of the container, disregarding the amount of foliage and exposure involved. Transpiration would be directly related to the amount of foliage present in each of the insolated containers. The authors further criticize deWit for using April-September evaporation rates at Akron, Colorado and stated that the reported alfalfa growing period was June to mid-October (the normal growing season at Akron begins long before June). This evaluation and the criticism of deWit's analysis is questionable and warrants further consideration. The authors conclude that alfalfa yield is directly correlated with pan evaporation throughout the United States (whole season values).

The authors also explored the relationship of the yield of individual cuttings to evapotranspiration and obtained a similar linear response. Harvested yield per unit of evaporation decreased from spring to fall and not necessarily in response to increasing evaporation rates. The authors believe that a storage retrieval cycle, in-so-far as food storage for alfalfa is concerned, accounts for this decrease, *i.e.*, cuttings one and two withdraw stored material from the roots, cuttings three and four seem to produce without either much retrieval or storage of material and thus are close to the seasonal average, cuttings five an six apparently contribute to root storage so that only a portion of the total production is harvested above the ground as hay.

The authors, however, overlooked the possibility that the disposition of net radiation and the extraction of sensible heat from warm air for a crop, such as alfalfa, is not necessarily the same as for an evaporation pan. That is, in the spring of the year the amount of sensible heat contributing to transpiration or evaporation may be negligible, but near the later part of the season, under high wind conditions in the Davis area, the amount of sensible heat utilized in transpiration and evaporation can be significant. If the pan responds differently than alfalfa, this can account for a portion of the change in relationship presented in Figure 5. Data obtained by Pruitt at Davis using ryegrass indicates a definite loop effect with evaporation being lower than evapotranspiration from February through June and greater than evapotranspiration from July through October. This is especially important on high wind days because on these days the ratio of E_t/E decreases to values as small as one-half of the normal ratios. For example when going from a fairly calm day to a dry, north wind day, E_t may double while at the same time evaporation from pans may be three to four times as high as on the calm day. Consequently, a significant portion of the curvature illustrated in Figure 5 and attributed to storage-retrieval might be a result of the differences in response of a crop and evaporation pan to climatic conditions.

The authors also explain the greater curvature shown in Figure 6 to a greater spring retrieval of dry matter at Geneva, New York as compared to Davis, California ; however, in Figure 4 it will be noted that the beginning of each season is shown as the final spring frost. In most northern areas of the united States it is not at all uncommon to find alfalfa growing four to six weeks before the final frost in the spring of the year. This amount of growth can contribute significantly to the first cutting yield and would probably explain a significant portion of the curvature shown in Figure 6. A specific example of the growth of alfalfa before the last frost can be illustrated by data from Kimberly, Idaho where in 1966 alfalfa began to grow about March 28. On May 23 alfalfa was 16 to 18 inches tall at the time the last frost occurred. Prior to May 23 there were four days with temperatures between 32°F and 30°F, five days with temperatures between 30°F and 29°F, four days with temperatures between 28°F and 27°F, four days with temperatures between 26°F and 25°F, one day at 24°F, two days between 20°F and 22°F and a low of 13°F on April 19. Alfalfa in this case was first cut on June 13. The conclusions concerning recommendations for the time of applying water based on the material presented in this paper would also be subject to question as well as the E_t/E ratios for the entire season if they were computed in a similar manner, although the seasonal effects would be much smaller. Some of the water use efficiency relationships would also be influenced as would the relative production functions The recommendations concerning the application of water during spring of the year and perhaps not during the warmest part of the year if water supply is limited, has in essence been practiced for many years in Syria (see report number 21 which indicates a high water use efficiency where the alfalfa is allowed to become dormant in July and August.

REPORT 33 : **Minimizing irrigation water use through management—by Stephen J. Mech (deceased) (USA)**

This report summarizes a study conducted from 1947-1951, with example data from alfalfa, potatoes, sugar beets, corn, and wheat experiments. The objective of this study was to determine the minimum amount of irrigation water that would be required if at each irrigation, only that amount of water necessary to raise the soil moisture to field capacity was applied. Three moisture levels and 12 replications (two replications of two slopes and three stream sizes) were involved. Water was measured onto and off each plot using HS flumes and water stage recorders. Irrigation water was applied when the average available soil moisture in the 122-cm profile reached 75, 60 and 35 per cent on potatoes and 60, 35 and 15 per cent for other crops. Soil moisture depletion was determined by gravimetric soil samples taken one or two days prior to an irrigation and 60 to 72 hours after irrigation was completed. The yields, sampling periods, number of irrigations, total water use, relative water use, and water use efficiency are summarized for each of the crops along with typical soil moisture depletion data.

The average water use efficiency on the medium and the dry treatment for all crops was 30 to 39 per cent greater than on the wet treatment, or 22 to 23 per cent greater if the potato crop is omitted. Detailed water use values between sampling dates are presented along with the ratios of consumptive use to evaporation. The ratios of consumptive use to evaporation on the wet treatment of alfalfa appear reasonable, but the ratios for the medium and dry treatment appear unusually low and may have been influenced by the extraction of water from below the 4-foot depth. The ratios of consumptive use to evaporation on sugar beets are excessively high on the wet treatment, especially near the end of the season, indicating that deep percolation may have represented a significant portion of the observed soil moisture depletion. The values for the medium sugar beet treatment are more reasonable except for the last sampling period which also indicated that deep percolation may have been involved in this depletion measurement. Seepage may have been occurring during some of the sampling intervals on the wet treatment of corn and also on the wet and medium wheat-alfalfa crops during the last sampling period.

These data indicate that when attempting to apply water to bring a soil to field capacity and then adding this amount to that observed prior to an irrigation to compute E_t, significant errors due to deep percolation may occur when high moisture levels are maintained. Several authors used this procedure in calculating E_t.

REPORT 34 : **A simulation technique to estimate crop production on irrigation projects, based on crop response to varying schedules of irrigation water—by Raymond L. Anderson and Arthur Maass (USA)**

This report describes a computer program designed to determine the most efficient allocation of limited irrigation water supplies to various competitive irrigated crops. It was developed on the hypothesis that in some years the demand for water exceeds the supply and decisions must be made to allocate these supplies. The computer program simulates water delivery systems, distribution rules, time and amount of irrigation water application, and estimated yield reductions associated with skipping or postponing specific irrigations throughout the season. Inputs consist of tabular data specifying a predetermined amount and frequency of irrigation water to be delivered to each crop in order that adequate soil moisture can be provided. This input is derived from estimates of evapotranspiration adjusted for average irrigation efficiency. Other inputs involve an estimated reduction in crop yield when a specified irrigation is not applied. Additional assumptions are involved when two successive irrigations are missed, and it is assumed that significant rainfall will not alter the irrigation schedule or requirement. A detailed description of the computer program is provided. The program is designed to handle twenty different rules for distributing irrigation water.

The reliability or value of a program such as this is almost wholly dependent on the accuracy and validity of the effect of soil moisture deficits on crop yields when irrigations are missed. Two successive misses, for example, were assumed to result in a total loss except for alfalfa. In the area under consideration, because of some precipitation, two misses on sugar beets in May and June, or the latter part of August and September, would not result in a complete crop failure. The effect of a delayed irrigation was not considered. Another weakness of the assumptions involved is that irrigation efficiency does not change as the water supplies are diminished. Historically, yields from irrigated farms in the Western USA have not diminished in water-short years and in some cases have actually increased because the farmer irrigates more efficiently. A computer simulation program is only as valid as the basic relationships that are considered in the analysis. Crude basic relationships used in the computation will result in only crude economic estimates for decision making regardless of the complexity of the computations.

REPORT 35 : Factors affecting determination of irrigation water requirements—by John W. Shannon and Norman MacGillivray (USA)

This report summarizes studies that are being conducted by the California Department of Water Resources, with particular emphasis on soil moisture storage, the use of available soil moisture added by one or more irrigations, and attainable irrigation efficiencies. The approach being used for estimating irrigation water requirements is described utilizing observations and data collected in the valley portion of the Tulare Lake Basin (the southern third of the great Central Valley of California) to typify results being obtained on a state-wide basis. The procedure described differs from many soil moisture budgeting methods in that a change in soil moisture level during any irrigation period may exceed, or be exceeded by actual evapotranspiration.

A general description of the area along with a climatic description involving air temperatures and precipitation, and additional details concerning the water supplies, distribution systems, the type of crops grown and future potential irrigated area are presented. The studies involve the determination of evapotranspiration, along with agro-climatic factors observed in standardized weather instrument sites. The major crops involved are plums, alfalfa, pasture, cotton, sugar beets and potatoes. The measured

E_t rate on irrigated pasture is assumed to be equal to potential E_t. The standard weather station enclosure includes black and white atmometers, an evaporation pan, and the usual temperature instruments.

Evapotranspiration for pasture compared to evaporative demand, as measured by a Class A pan, averages about 0.8 throughout the year. Consequently, in the remainder of the paper, E_t rates are expressed as ratios, E_t/E_p, to eliminate monthly climatic variations. This ratio was found to vary with percentage of ground cover, soil moisture, soil surface condition, and crop roughness. Fot example, E_t/E_p equals or may exceed the ratio for pasture if the soil is maintained continuously wet during a given period, such as when the plants just begin to emerge and have little ground cover.

The Tulare Basin is subject to advective energy, consequently, crop surface roughness also affects the ratios by increasing the utilization of advected energy. An example of the influence of ground cover and surface roughness is illustrated with cotton which indicates that the ratio increases and approaches 1.0 at about 30-35 per cent ground cover. The ratios are unaffected by soil moisture over a wide range of available soil moisture for crops having a well-developed root system, such as an orchard, where the ratios begin to decrease only when available soil moisture had been reduced to 5-10 per cent.

Factors influencing maximum utilization of precipitation are discussed as are procedures for maximizing the storage of precipitation during the rainy period. A specific example of the soil moisture accretion-depletion method is presented to illustrate the influence of a deep rooted crop following a shallow rooted crop. In conclusion, the authors indicate that the budgeting method proposed results in more realistic estimates of month-to-month water requirements than can be obtained by the more common procedure of providing irrigation water in amounts equal to monthly E_t.

REPORT 36: **Irrigation requirements from evaporation—by J. E. Christiansen and G. H. Hargreaves (USA)**

This report describes three equations for estimating evaporation from a Class A pan, and four equations for estimating potential evapotranspiration, which is considered equivalent to E_t from ryegrass as measured with a 6.1 m diameter weighing lysimeter installed in a standardized environment. The authors state that evaporation from a standard pan is perhaps the best single index of climate as it pertains to evapotranspiration. However, they carefully point out that when standards for installation are not adhered to, evaporation may exceed that from a standard installation by as much as 20 per cent. The various factors affecting pan evaporation are discussed along with a review of recent articles relating E_t to evaporation. Specific formulas for estimating pan evaporation are reviewed—Hargreaves and Christiansen. Four new formulas for estimating potential E_t using ryegrass data collected by Pruitt are presented. These formulas involve measured pan evaporation, extraterrestrial solar radiation, and incoming observed solar radiation as bases, and a formula of the Hargreaves type adapted to the California data. The report also includes a general summary of the use of E_t data in planning irrigation systems, and crop coefficients relating evapotranspiration to either potential E_t or pan evaporation. Details are provided for each of the equations and the crop coefficients involve alfalfa, avocado, citrus, dates with heavy cover, deciduous orchard, grapes, orchard with clover, oranges and lemons, pasture grass, bahia grass, burmuda grass, pangola grass, trenza grass, platano, sugar cane, walnuts, beans, cotton, corn, grain sorghum, spring grain, winter grain, melons and cantaloupe, nuts—pecan, peanuts, potatoes, rice, soybeans, small vegetables, sugar beets, tomatoes and vegetables, all expressed as coefficients *versus* per cent of growing season.

REPORT 37: **Irrigation requirements of rice—by D. Doddiah (India)**

This report reviews the various factors affecting irrigation water requirements of rice and the two extreme views concerning the irrigation of rice—(1) rice is an aquatic plant and needs continuous submergence, and (2) rice can stand intermittent irrigation. Experimental studies were conducted at the Experimental Farms at Nagenahally and at Mandya, and at five privately owned farms over a period of three years. The first study at Nagenahally involved three irrigation levels (4,470, 5,110 and 5,740 mm), three irrigation intervals (daily, once in two days, and once in three days), and two nitrogen levels (33.7 and 67.3 kg per ha). Various cultural practices are described along with the allocation of irrigation water for each level throughout various stages of growth. Rainfall was evaluated by neglecting amounts less than 6.4 mm and by adjustments in the amounts of irrigation water applied depending on the amount of rainfall received. Detailed descriptions of these and modifications of these treatments are presented which involve daily irrigations to maintain water at a depth of 25, 38 and 50 mm; irrigation once in four days to maintain 50 mm of water during the crop period; 13 mm applied daily; 13 mm daily plus 16.5 mm extra daily during rooting stage; the same as the previous treatment but with the 16.5 mm extra during flowering stage; the same as the previous but with 16.5 mm extra during the rooting and flowering stage; irrigation on all days to maintain 50 mm of water; irrigations 3, 4, 5 and 6 days a week to maintain 50 mm of water. Similarly treatments for the study at the Mandya farm are described along with detailed plot layout and cultural procedures. Total rainfall, irrigation, nursery and crop periods, and yields are presented for each treatment along with soil chemical analyses.

The author concluded that: (1) The quantity of water required by the crop is not constant for the same plot during different seasons; (2) there is no need to maintain submergence continuously, nor is it required to maintain overflow from the plots; (3) intermittent versus continuous submergence does not increase growth of weeds; (4) with good land preparation, and larger plots, better water control and water use efficiency are possible; 3,830 mm, including rainfall, is required in the area represented by the experimental area; and (5) the soil moisture regime method for irrigation can be adopted to a rice crop except in soils where field capacity is very low.

Suggestions for future research to determine water requirements on large areas are recommended. Also, since irrigated agriculture represents a vast industry in India, in order for this industry to provide maximum return, some sort of "field control" to regulate water according to the needs of the crop is recommended.

REPORT 38: **Regional and seasonal tendency of evapotranspiration in paddy field of Japan and measurement methods—by Shoichiro Nakagawa (Japan)**

This report summarizes the results of detailed studies of evapotranspiration in paddy fields, descriptions of evapotranspiration measurement techniques designed by the author, and practical methods of estimating evapotranspiration in Japan. The study involved data collected in 37 districts which were tabulated (a total of 122 year-locations) in 1957, and additional data collected after that time. Only those data collected in a "box" with a bottom, placed in paddy fields were used. All data collected in pots, etc., with unnatural environments were excluded. The most common cropping periods for each district were chosen, and only those locations having two or more years of data were used. These locations were grouped into ten districts of different meteorological conditions and mean values for each 10-day period were obtained.

The report contains an excellent summary of mean measured evapotranspiration. The values range from 3.5 to 7.5 mm per day with peaks occurring near the end of July to the middle of August in all regions. Total evapotranspiration ranges from 440 to 550 mm and averages about 500 mm for a 100-day period. Representative data for early, normal, and late season crops are presented graphically. The author concludes that the variation in water use is influenced more by meteorological conditions than the growth stage of the paddy. The total seasonal E_t decreases in the order of: Normal season, early season and late season primarily due to the different growing periods—105, 100 and 80 days, respectively.

Evapotranspiration was related to evaporation from a small cylinder 20 cm in diameter and 10 cm in depth. These ratios are summarized for the normal cropping period by months for each of the regions. The mean values of all locations for normal, early, and late season cultivations are also provided. In general, the ratio E_t/E tends to become large on cloudy and rainfall days.

An excellent summary of various methods of measuring evapotranspiration is presented along with a detailed description of the box (1 m $\times$ 1 m containing about 20 plants) used for measuring evapotranspiration in a rice paddy. The author concludes that because of the large variation in percolation encountered in rice fields, it is impractical to investigate E_t in detail in each paddy field. Instead, estimates of E_t using the mean values presented are suitable for determining this component of irrigation water requirement. The author also concludes that even if the growth and yield of the paddy increased and the density of cultivation is raised, E_t will not increase greatly as compared to percolation rates of 15 mm per day or more. These small E_t changes can be accounted for by merely adding 1 mm per day to the peak values presented.

REPORT 39 : **Variation of soil moisture and change of consumptive use of water and yield of crops—by Kenji Shiina (Japan)**

This reports summarizes the results of experiments to evaluate the absorption of water by plants as soil moisture tension increases. The first study was conducted at the Agricultural Engineering Research Station at

Hiratsuka City, Kannagawa Prefecture from 1960 to 1962. This experiment involved the use of a floating lysimeter to measure daily evapotranspiration after August 1 with upland rice planted at the end of June. Tensiometers, spaced 10 cm, were installed in the soil tank to measure changes in moisture tension. The change in water absorption was determined by using the relationships between E_t and evaporation determined at the same site from 1953 to 1958. These ratios averaged 0.83 from June to the middle of July, 1.26 from the end of July to the beginning of August, and 1.95 from the middle of July until the middle of September. (From these large values, it appears that the rice grown in these lysimeters were not adequately surrounded by a similar crop and consequently the values obtained, though perhaps indicative of the influence of soil moisture, would probably not be indicative of field conditions).

The results indicated a general decrease in evapotranspiration when the stored water approached 150 mm on a sandy soil and 375 mm on a volcanic ash soil, but E_t remained essentially constant at water contents above this value. In general, the evapotranspiration decreases when about half of the root zone has a *pF* greater than 3.0.

The effect of decreasing soil moisture and evapotranspiration on yield was based on studies conducted in 1957 and 1958. These studies involved small containers (20 cm in diameter × 45 cm in height) placed in the soil. (No mention is made of the surrounding environment). The results indicated that when soil moisture decreased so that evapotranspiration decreased, the yield also decreased.

A field study was conducted from 1964 to 1966 using a mixed grass-clover crop to evaluate the trends from the lysimeters. Three moisture levels were imposed (no irrigation, *pF* exceeded 3.0 in August and September ; soil moisture tension kept below *pF* 2.5 by irrigations ; and a small amount of irrigation to maintain the soil moisture tension below *pF* 3.0 to 3.3 in August and September). The soil moisture consumptively used was calculated either from tensiometer data with the tensiometers placed from 10 cm to 80 cm, or by soil sampling. The results indicated that when the soil moisture decreased so that the *pF* increased to more than 3.0 for 15 days in August, consumptive use and yield decreased.

REPORT 40 : **Experimental studies of soil moisture movement and consumptive use of water (ET) in Tangerine orchard irrigation— by Yoshikazu Fujioka and Yoshihiro Kaida (Japan)**

This report summarizes the results of several experiments, conducted from 1962 to 1966, to develop the sprinkler irrigation method on Unshu-tangerine orchards on sloped land. The objectives of the study were to evaluate the characteristics of the spray with and without wind on flat and sloped land, water losses during sprinkler irrigation, the disturbance in distribution due to the interception by foliage, the movement of applied water during and after infiltration, and the movement of soil moisture associated with soil drying. Soil characteristics for the sites are summarized.

In the first study, the infiltration was evaluated using glass-filter electrical resistance blocks spaced at 10 cm intervals from 5 to 55 cm. The results indicated that when the precipitation intensity is less than infiltration capacity, the wetting front advances without forming a saturated zone.

The second study involved the horizontal distribution of water during and after irrigation. This study was conducted to evaluate the assumption that the over-tree sprinkler irrigation pattern would be disturbed by the foliage, but such nonuniform distribution would become uniform by diffusion and movement of soil moisture. Resistance blocks were placed at 1-m intervals (13 points) in a straight line representing a cross section of a tree to evaluate the distribution of water and the variation of soil moisture at each point after an irrigation. In addition, the variations in soil moisture caused by a 50-cm diameter interceptor on flat land and a 1-by 2-m interceptor on sloped land were evaluated by soil sampling. The results indicated that 24 hours after sprinkler irrigation there was some improvement in the uniformity coefficient on flat land. Soil moisture at a depth of 10 to 20 cm was not influenced by the 50-cm interceptor, and at a depth of 0-10 cm it was not influenced except in the case of complete interception. The authors concluded that the distribution disturbance need not be considered on either the sloped or flat land.

Consumptive use studies of the tangerine trees were made in the next series of tests by sampling 4 to 10 points about single trees to a depth of 55 cm using glass-filter blocks. A summary of the horizontal and vertical root distribution is presented along with soil moisture content and tension profiles after sprinkling. A summation of evapotranspiration at various sites between trees, under the edge of the crown, and under the crown is presented graphically. The authors indicated that 90 per cent of the moisture is withdrawn from the 0-20 cm layer with the influence of evaporation becoming greater near the soil surface. They also concluded that the root zone in a humid region as in Japan is generally shallow and that upward movement of soil moisture under the main root zone was expected to be about 15 to 20 per cent of the total consumptive use.

REPORT 41 : **Application of efficient irrigation as affected by crop water requirements—by Faustino Garcia Lozeno and Alberto Losada (Spain)**

This report summarizes the general importance of knowing the optimum, peak, and seasonal water requirements, and reviews the present status of irrigation development in Spain. Two experiments were conducted from 1960 to 1966—one involving gravity irrigation and the other sprinkler irrigation. These were conducted at the El Encin farm in the Province of Madrid. The weather station and lysimeter were installed near the gravity irrigation site. The crops studied were : wheat, sugar beets, late potatoes, maize, lucerne, and beans grown for grain. The gravity plots were 80 by 24 m and the sprinkler plots were 58 by 40 m. Irrigation was determined when Bouyoucos blocks placed at a 30 cm depth indicated 30 per cent available water remaining. Blocks were also placed at 60 cm to indicate the depth of penetration of irrigation water. Sample forms for the recording and plotting data are presented. The results for an additional three-year study, 1965-67, with sprinkler irrigation at La Poveda Experiment Station are also presented.

A summary of mean monthly temperature, rainfall, and E_t estimates using the Thornthwaite and Blaney-Criddle equations, and water required using sprinkler irrigation as the standard is presented for alfalfa during each year of the first study. In the discussion of peak demand, the authors indicate that calibration coefficients for the various formulas are required based on the crop and soil texture. They report that the annual consumption for maize with gravity irrigation at El Encin was 512 mm as compared to 383 with sprinkler irrigation, and similarly for alfalfa 922 mm with gravity as compared to 547 mm with sprinklers. These values are questionable if they represent only evapotranspiration. If they also include drainage, then they may be representative. As the result of these studies, the authors indicate a savings in water with sprinkler irrigation as compared to gravity irrigation which ranges from a minimum of 25 per cent in the case of corn to a maximum of 49 per cent for beans.

A brief summary of a study to evaluate the production by various wheat varieties is also presented. In this study, the soil moisture was depleted to 30 and 50 per cent before irrigation along with a non-irrigated treatment and a treatment where the soil was kept near field capacity all season. These results indicate that yields of all varieties were reduced at the 50 and 100 per cent levels as compared to the 30 per cent levels. The general decrease in yields with each of the 5 years, and the decrease within a given year at the higher moisture levels indicates that a deficiency of a nutritional element, such as nitrogen, may have limited production.

REPORT 42: **Evaluation of water requirements of crops in Portugal—by Manuel Miguel de Sousa Dias, and António Lousada dos Santos (Portugal)**

This report summarizes the results of experiments carried out at a new experiment station in Montes Velhos from 1960 to 1967. Six plots, each containing 1,000 m², and irrigated by furrows and border strips were used. The site also had a weather station, including atmometers, and evapotranspirimeters filled with grass. The lysimeters were 1 m square and contained 70 cm of soil. Each of the six plots was also equipped with two evapotranspirimeters. The plots were irrigated whenever the soil moisture decreased to 60 per cent of the available capacity. The soils were sampled on the first, eleventh, and twenty-first day of each month to a depth of 1 m using 10 sampling sites per plot and four samples per site. Evapotranspiration was calculated by the difference in soil moisture plus precipitation and irrigation water that was applied during the 10-day period (With this method of calculation there is some possibility of deep percolation occurring). The crops involved were wheat, peas, beans, Alexandrian clover, maize for grain and forage, potatoes, beets, tomatoes, pimentoes, alfalfa, and Cornell meadow.

The E_t results from the lysimeters are presented graphically in mm per day for each of the crops. The values for some crops, such as alfalfa, appeared to be quite high, 11 mm per day as compared to grass which was about 7.1 mm per day. Ratios of evapotranspiration for each crop to evapotranspiration of grass are also presented in tabular form by months. The ratio of alfalfa to grass is as high as 1.73 which is questionable.

The results from the field data do not agree with the evapotranspirimeter data. Most of the field E_t values were below that of grass (in the evapotranspirimeter the E_t values were greater than those of grass). The authors concluded that the E_t rates measured in evapotranspirimeters are generally double the ones obtained by field measurement and they attributed this difference to daily irrigation in the evapotranspirimeter tanks which always kept the soil surface moist. Also, the walls of evapotranspirimeters prevented free exchange of heat with the soil resulting in a higher concentration of heat energy. (The environment surrounding the lysimeter was not given—and may have been a significant factor.) The peak value for grass in the lysimeters was about 7 mm per day whereas the field determinations of E_t for all crops generally ran from 3 to 4 mm per day.

The field data were also expressed in relative terms using alfalfa as the reference. A comparison of E_t values for alfalfa and estimates of E_t by Penman, Thornthwaite, and Turc's equations are presented along with the values from the Livingston atmometers. An excellent summary of monthly and seasonal coefficients for the various crops for each of the equations are presented. However, because of the variations mentioned above, this reporter questions the reliability of the coefficients.

REPORT 43 : **Correlation between crop yield and consumptive use under irrigation conditions—by M. Botzan, O. Merculiev, S. Morgenstern, and T. Cioica (Rumania)**

This report did not reach this reporter in time to permit a complete translation prior to the preparation of the General Report.

The report summarizes previous studies conducted between 1952 and 1960 in the Danube Plains using four fields located in various climatic-soil zones from a dry steppe to a forest, and similar studies conducted in other areas. More recent data, 1952-1965, are also summarized in this report.

Generalized relationships between production and consumption of water (characterized by an S curve) are presented and discussed. Three phases of the production-consumption relationships corresponding to moderate, optimum and excessive water use, are analyzed and characterized analytically for various crops, such as lucerne and hybrid maize.